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# FINAL REPORT

*EM Visualization*
*of*
*Printed Circuit Board Assemblies*



## A Phase I SBIR
## on behalf of
## USAF; SA-ALC/LDAE

Contract F41608-94-C-1115

Reporting Period; 6/20/94 through contract completion

All material in this report is unclassified

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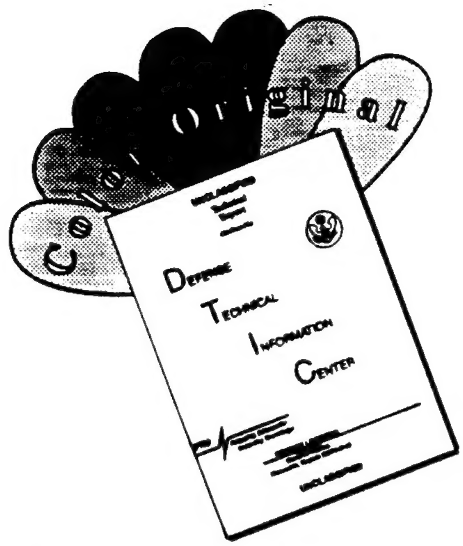


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# Introduction

## *Requirement*

Presently, the ability to rapidly collect reliable information about the detailed condition of a functionally suspect printed circuit board assembly (PCBA) is marginal. This data is necessary, to assure rapid and reliable PCBA repair, thereby maximizing uptime, minimizing spares stocks, etc. The need is real for both commercial and US government applications and becomes critical as electronic products become more complex (eg: one cannot treat expensive boards as expendable).

## *Objective*

Provide initial work demonstrating 'proof of principle' that an EM visualization system can be developed, with the capability to assess the functionality of PCBAs. In a production evaluation the system must be capable of rapid, reliable operation by technician level personnel.

## *Baseline*

A personal computer controlled device, the EMSCAN, was identified, with the capability of collecting both spectral and spatial scans of PCBAs and displaying the scans. To date the unit has primarily been used as a design aid for engineers. Data acquisition (particularly the spectral data) is slow, tedious and error prone. Data analysis required extended practice, an intimate knowledge of the PCBA's operating characteristics and considerable intelligence on the part of the user.

It was anticipated that the discrimination inherent in having available both spectral and spatial data, enhanced by color visualization, could provide a uniquely definitive basis for data processing.

## *Results*

The phase 1 SBIR:

- Demonstrated that it is practical to test suspect PCBAs to identify failure areas.
- Demonstrated that identification of fault modes is manually possible in simple cases, but will require a suitably trained learning neural network for practical boards.
- Identified and characterized the capabilities and limitations of the existing EMSCAN for the required application.

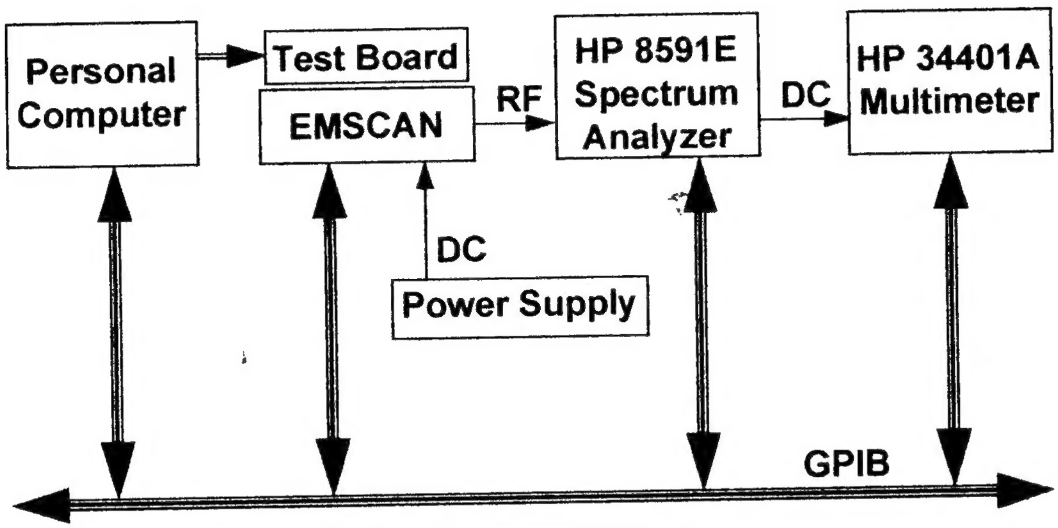
- Identified and specified the form of improved hardware and software to provide real-time data acquisition and near-real-time analysis, which should be effective in meeting the practical requirements of a field system.
- Specified the form of a neural network, necessary to reliably manage the complex and volumes data generated by acquisition and analysis.
- Determined the extent necessary and scheduled a follow-on effort to create and test an operational prototype system.
- Opened discussions intended to maximize the probability of successful commercialization of the anticipated final capability.
- Arranged for DCAA audits resulting in an acceptable accounting system.

## Technical Discussion

### *Early Work*

The test setup is shown below.

**System Block Diagram**




The operating test procedure consisted of the following process.

- Wide bandwidth spectral scans of the powered normal test board, using all the sensors beneath the test board, to determine frequency spans of interest.
- Narrow bandwidth spectral scans of the powered normal test board at the initially acquired frequencies, using all the sensors beneath the test board, to determine frequency peaks and valleys.
- Narrow bandwidth spatial scans of the powered normal test board, using all the sensors beneath the test board. These are the baseline spatial scans.
- Narrow bandwidth spatial scans of the powered abnormal test board, using all the sensors beneath the test board. These are the special spatial scans.
- Calculate ratios of the abnormal spatial scans to the normal scans. These ratio scans quickly reveal the faults in the board's EM signature, and therefore, the board.

Several lessons were learned during data acquisition.

During initial tests we noted that the EMSCAN operating program did not have the safety protections and user friendliness expected in modern Windows programs. It is possible to go through the entire acquisition process without connecting the EMSCAN to the controlling computer or the spectrum analyzer.

Our initial data acquisition process used a multifunctional, complex PCBA (termed the 'DT' board). We elected to process the PCBA on the component side only. Our PCBA setup format was to:

Data were acquired for the blank EMSCAN unit, with the unpowered DT board and the powered DT board under normal conditions. In recognition of the limited time we had available for data acquisition, considerable data were collected for later analysis.

- Iterate numerous spectral scans at various frequencies. This process took an extremely long time and was tedious. Since the setup was totally manual it was subject to errors and omissions.
- Identify the twenty frequencies with the highest amplitudes.
- Acquire spatial scans at these frequencies for analysis.

The entire process was complex and judgmental in nature.

Our failure test format (the processing that would be required to assess a suspect PCBA in a production or test operation) was as follows:

- Open the input power lead to a component on the PCBA.
- Repeat the standard spatial scan processing, collecting data for the open.
- Attach a variable power supply to the input of the component and set at the normal voltage. Repeat the standard spatial scan processing collecting data to identify what perturbation was caused through the rewiring.
- Replicate the above process at various voltages (simulating an underpower condition), including 0 volts (simulating a short).

In processing ratios of spatial scans using the EMSCAN software and performing the analysis we noted the following:

- In each test case, identification of differences due to the induced fault was discernible at some (but not all) frequencies. The differences ranged from large and easy to spot to requiring an extended search for location. Sometimes a variation was noted remote from the fault. In sum, identification of a fault was successful, although no appreciation was gathered as what could be accomplished without multiple boards, a neural network, automated processing aids, etc.

- An overwhelming quantity of data was acquired.

- The EMSCAN software performs extensive interpolation of the data to provide an assessment of the PCBA signal between EMSCAN sensors. While such interpolation is wise in that it enhances the visual identification of board components, it dilutes the data and is not suitable for calculational assessment. EMSCAN stores the data in tabular form.

A change of direction was necessary. Accordingly:

- After some abortive exercises we selected a simple board designed as a parallel printer card for a PC. There were only four active integrated circuit's (IC) on the board. This provided a clearer picture and reduced the data volume, thereby allowing for manual processing.

- Data were collected with the EMSCAN then imported into Excel, a Microsoft Windows spreadsheet, for calculational assessment.

- Excel provided a robust platform for calculations. Simple variations in the visual display enhanced interpretations significantly.

- The checkerboarding of active sensors (some sensors active, others not), in order to reduce acquisition and processing time is risky and has been rejected.

- The use of board shifting (on the EMSCAN sensor plate) to enhance resolution, by synthetically increasing the density of EMSCAN sensors, has been considered. (A determination of the value of this technique must await sufficient automatic aids for processing complex data.)

- Interpolation between sensors is appropriate for judgmental visualization only. It introduces surmised data and is an unnecessary risk for automated processing.

- Identification of massive failures (opens, shorts) of IC's is straight forward.

- Location identification of the failure of IC's with partial power applied can be accomplished when the applied power is a small fraction of normal. However, as the applied power approaches the specified power, the ability to discern the failure diminishes. It is suspected that there is no general rule correlating underpowered components to component failure (eg: it is component dependent).

- Identification of failure locations on passive components is more complex. Following the simulation of a failure by shorting the capacitor component of an RC noise filter, an effect was noted on the resistor and on the IC driving the filter, but not on the capacitor. A suitable learning network will address this type of complication

### *Analysis Effort*

This effort is divided into two sections: Proof of principle of the technical approach and preliminary assessment of ancillary effects.

**Proof of Principle** (See Appendix 1 for data and detailed interpretations)

- Identification of known faults IC faults was accomplished. Passive component faults can yield markers, both at the fault and at remote locations, but generally the marker at the fault was of the highest amplitude and most prominent.
- Attempted resolutions of signal ratios of less than + or - 10dB resulted in noise clutter defeating the effort. Accordingly, for reliable interpretation, the presentation slides do not display data for this range of values. Board characterization should clarify suitable 'normal noise' levels for suspect board testing.
- Spatial data were acquired at spectral peaks and valleys. Useful data were obtained in both cases, but the spatial valley data were clearer and easier to interpret.
- To date, an optimum technique for prediction of suitable spatial frequencies for test has not devised, excepting through characterization of each board type.

**Ancillary effects** (See Appendix 2 for data and detailed interpretations)

- A component on 2 'identical' boards made by different manufacturers is identifiable. However, the differences are small with respect to faults and are not expected to disrupt fault identification. The possibility of having a statistically standard EM board overlay may be real, subject to quantity assessments.
- IC failures (short, open, underpowered) are easily identifiable as long as the underpowerd mode is significant. As the underpowered mode approaches normal power the ability to discern the difference wanes. There may be side effects from artificially powering the board in the underpowered tests, which may be masking real data.
- Card displacements on the EMSCAN with respect to sensor locations seem to be permissible up to approximately 25% of the sensor-to-sensor dimension.
- X-ray/EM spatial scan overlays were attemped as a means of adding to the determination of fault locations. Software formats and limitations aborted this effort, as one could not mix bit maps and ratio maps. Suitable software (PV-Wave) has been selected for any follow on effort, to aid this form of visualization, as well as supporting real time visualization and analysis.

## *Outside Capabilities*

As the testing and analysis proceeded, numerous technologies were identified that will be necessity to create a practical, useful field system. Research of the marketplace has identified capabilities which will permit engineering solutions to these issues. The basic measurement tools exist (or are coming to market) to create a practical field system.

### EmscanQ Device (see Appendix 3 for detail)

A complete spatial scan once per second is a major point mentioned in the EmscanQ literature. Such an anticipated data acquisition time is competitive with any other emerging technique and resolves concerns we have had regarding efficiency of data acquisition and analysis.

The emerging ability to make time related scans (not yet supported by EmscanQ) provides promise of the the capability to detect 'soft' failures (probably a major cause of 'shop queens') related to timing, etc. This capability is deemed essential to ultimate repair of such failures at the depot level. Ref: private communication with C. G. Hoover; Senior test engineer at General Technology Corp., a manufacturer of military aircraft PCBA's

Time related scans of potential value include:

- Extended Sample scans at a single frequency, on a single probe.
- Repetitive spatiall scans, or multispatial scans, at a single frequency.
- Repetitive spectral sweeps, or multispectral scans, on indidual probes.

### Neural Network Support (see Appendix 4 for detail)

Under the DOE SBI program, the support of the Sandia National Laboratory (SNL) has been requested in identification of a neural network (NN) to serve as a utility driven classifier (final agreement must await award of a follow on effort). The NN will perform several functions. Following the initial broad bandwidth spectral scan it will choose the frequencies for narrow bandwidth spectral investigations. That data will be utilized to select specific frequencies for spatial scans. Finally, spatial scan ratios will be used by the NN to determine locations and types of faults. It is believed the NN will be a supervised and probabilistic. The current selection for the NN is NeuralWorks Professional II/Plus, a product of NeuralWare.

### Real Time Data Acquisition Support (see Appendix 5 for detail)

The assistance of Los Alamos National Laboratory (LANL) has been requested for support in Windows based control software to facilitate device setup and data acquisition. Note that Lab-View was selected as the primary graphical programming language because of it's flexibility, it's ability to work under a wide range of platforms and LANL's extended experience with LabView.

Certainly this determination is tentative, as we have noted characteristics in PV-Wave which seem to be particularly applicable.

## Beta Site Location

Discussion is underway with General Technology Corporation, a local manufacturer of PCBAs for the military, to assure the quantities of boards necessary to validate the operation of the test system in an controlled environment.

## Commercialization

An agreement in principle has been reached with Amplifier Research to market the standard production system and capability, which is envisioned upon completion of the follow-on, in the U.S. As Amplifier Research will also be marketing the EmscanQ, they will have identified and characterized the customer interest and needs well in advance of this systems availability.

At the end of a possible phase 2 effort, work will focus on enhancements and improvements of the basic system, as well as on marketplaces which have unique needs for the basic system.

## *Follow on Start-Up*

H&A Inc. is concerned about the integration of a wide range of new hardware and software, much of it scarcely completing Beta Site testing. Accordingly, any follow-up effort we perform will start with a two month period during which time we will:

- Attend equipment demonstrations and/or visit sites with equipment that can be assessed in detail.
- Effect a systems study to assure that the integration of the various hardware and software is identified and understood.

Only at that point will equipment be ordered, support hired, etc. to effect a typical phase 2 type effort.

# Appendix 1

## Printer Card Analysis (Basic)

A description of the images following are:

2. A spectral scan of the powered print card A in its normal configuration. The 300 Hz bandwidth scan ranged from 10 MHz to 370 MHz, half the EMSCAN's (10 MHz to 750 MHz) range. Note that the first major peak is near 33 - 34 MHz with an amplitude of ~70 dBuV.

3. A spectral scan of the powered print card A in its normal configuration. This 10 HZ bandwidth scan ranged from 32.47 MHz to 34.32 MHz. Note that the high amplitude area does not resemble an impulse peak, but rather a Gaussian shape. Spatial scans were acquired at the five highest and five lowest amplitudes of this spectral scan. These scans were acquired with the card powered, in normal and abnormal conditions.

4. A spatial scan of the powered print card A in its normal configuration, frequency = 34.19 MHz, bandwidth = 10 HZ. (The row and column indices are marked along two sides of the scan. See the photograph for component locations corresponding to (row, column) locations on the figures.)

| Position | Amplitude | Component |
|---|---|---|
| (12,12) | 30 - 40 dBuV | chip: U1 |
| (12,15) | 30 - 40 dBuV | chip: U4 |
| (14,11) | 30 - 40 dBuV | chip: U1 |
| (15,14) | 30 - 40 dBuV | chip: U3 |
| (16,13) | 30 - 40 dBuV | capacitor: C3 |

5. A spatial scan of the powered print card A with the power input leg of integrated circuit U4 shorted to ground: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,16) | 30 - 40 dBuV | chip: U4 |

6. A ratio of the two previous spatial scans: short @ U4/normal: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (12,12) | -20 - -10 dB | chip: U1 |
| (11,15) | -20 - -10 dB | chip: U4 |
| (14,13) | -20 - -10 dB | chip: U2 |
| (17,11) | -20 - -10 dB | 5 Vdc power source |

| | | |
|---|---|---|
| (17,14) | -20 - -10 dB | 5 Vdc power source or capacitor C2 |

7. A ratio of two spatial scans: short @ U4/normal: frequency = 34.23 MHz, bandwidth = 10 hz. Note some of the lowest amplitude areas:

| Position | Amplitude | Component |
|---|---|---|
| (11,15) | -20 - -10 dB | chip: U4 |
| (16,14) | -20 - -10 dB | capacitor: C3 |
| (18,13) | -20 - -10 dB | 5 Vdc power source |

8. A ratio of two spatial scans: short @ U4/normal: frequency = 34.30 MHz, bandwidth = 10 hz. Note the lowest amplitude areas:

| Position | Amplitude | Component |
|---|---|---|
| (11,15) | -20 - -10 dB | chip: U4 |

- Using any of these short @ U4 spatial scans, if can be seen that a difference exists between the normal and abnormal states of the printed circuit card. The ratio of scans show integrated circuit U4 to be in an abnormal state.

9. A spatial scan of the powered print card A with the power input leg of integrated circuit U4 open: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,16) | 30 - 40 dBuV | chip: U4 |

10. A ratio of two previous spatial scans: open @ U4/normal: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (11,14) | -20 - -10 dB | chip: U4 |
| (11,15) | -20 - -10 dB | chip: U4 |
| (14,13) | -20 - -10 dB | chip: U2 |
| (17,14) | -20 - -10 dB | 5 Vdc power source or capacitor C2 |
| (18,12) | -20 - -10 dB | 5 Vdc power source |

11. A ratio of two spatial scans: open @ U4/normal: frequency = 34.23 MHz, bandwidth = 10 hz. Note the lowest amplitude,

| Position | Amplitude | Component |
|---|---|---|
| (11,15) | -30 - -20 dB | chip: U4 |

12. A ratio of two spatial scans: open @ U4/normal: frequency = 34.30 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (11,15) | -20 - -10 dB | chip U4 |
| (12,13) | -20 - -10 dB | capacitor: C14 (adjacent to U4) |
| (12,15) | -20 - -10 dB | chip: U4 |
| (14,11) | -20 - -10 dB | chip: U1 |
| (14,14) | -20 - -10 dB | chip: U2 |
| (16,11) | -20 - -10 dB | 5 Vdc power source |
| (16,15) | -20 - -10 dB | chip: C3 |
| (17,13) | -20 - -10 dB | 5 Vdc power source |

- It can be seen, using any of these open @ U4 spatial scans, if that a difference exists between the normal and abnormal states of the printed circuit card. The ratio of scans show integrated circuit U4 to be in an abnormal state. Further, the differences are distinct from those noted with the integrated circuit shorted.

13. A spatial scan of the powered print card A with capacitor C12 shorted: frequency = 34.19 MHz, bandwidth = 10 hz. Note the 30 - 40 dBuV amplitude areas along rows 9, 11, 13 & 16.

14. A ratio of two previous spatial scans: short @ C12/normal: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 8,10) - (11,10) | -20 - -10 dB | resistors: RP1 |

15. A ratio of two spatial scans: short @ C12/normal: frequency = 34.23 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 8,10) - (12,10) | -20 - -10 dB | resistors: RP1 |
| ( 8,13) | -20 - -10 dB | ? |

16. A ratio of two spatial scans: short @ C12/normal: frequency = 34.30 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 8,10) - (14,10) | -20 - -10 dB | resistors: RP1 |
| ( 8,13) | -20 - -10 dB | ? |

- Again a difference between the card's normal and abnormal states is noted. The ratio of scans depicts the majority of the activity in the vicinity of the resistors. Perhaps this is due to a RC circuit.

17. A spatial scan of the powered print card A with input power to integrated circuit U4 open and capacitor C12 shorted: frequency = 34.19 MHz, bandwidth = 10 hz. Note the (dis-)similarities between this double fault scan and the previous single fault scans.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,16) | -20 - -10 dBuV | chip: U4 |

18. A ratio of two spatial scans: open @ U4 & short @ C12/normal: frequency = 34.19 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,13) | -20 - -10 dB | Capacitor: C12 |
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (11,15) | -20 - -10 dB | chip: U4 |
| (12,15) | -20 - -10 dB | chip: U4 |

19. A ratio of two spatial scans: open @ U4 & short @ C12/normal: frequency = 34.23 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| (11,15) | -30 - -20 dB | chip: U4 |
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (13,12) | -20 - -10 dB | chip: U1 |
| (14,14) | -20 - -10 dB | chip: U3 |
| (16,14) | -20 - -10 dB | capacitor: C3 |

20. A ratio of two spatial scans: open @ U4 & short @ C12/normal: frequency = 34.30 MHz, bandwidth = 10 hz.

| Position | Amplitude | Component |
|---|---|---|
| ( 9,14) | -20 - -10 dB | chip: U4 |
| (11,15) | -20 - -10 dB | chip: U4 |
| (12,13) | -20 - -10 dB | Capacitor bank |
| (12,15) | -20 - -10 dB | chip: U4 |
| (13,14) | -20 - -10 dB | ? |
| (13,15) | -20 - -10 dB | chip: U4 |
| (14,10) | -20 - -10 dB | chip: U1 |
| (14,12) | -20 - -10 dB | chip: U1 |
| (14,14) | -20 - -10 dB | chip: U1 |
| (16,13) | -20 - -10 dB | capacitor: C2 |
| (16,14) | -20 - -10 dB | capacitor: C3 |
| (18,13) | -20 - -10 dB | 5 Vdc power source |

- There are a greater number of differences noted here than in any other scans due to two faults. No RC circuit signatures are evident, yet the open U4 integrated circuit is obvious.

21. Conclusions.

1. At certain frequencies, faults in the circuit board generate easily observed differences in the spatial scans.
2. Different faults generate distinct spatial differences.
3. Opens If the board contains multiple faults, the highest magnitude ratio difference is obvious. This suggests a stepwise correction of faults: scan and repair the most obvious, scan and repair the new most obvious, etc. and shorts of integrated circuits are distinguishable and the faulted component locatable.
4. Shorted capacitor signatures are observed, yet not (necessarily) in the vicinity of the capacitor.

## *Conclusions*

1. At certain frequencies, faults in the circuit board generate easily observed differences in the spatial scans.
2. Different faults generate distinct spatial differences.
3. Opens and shorts of integrated circuits are distinguishable and the faulted component locatable.
4. Shorted capacitor signatures are observed, yet not (necessarily) in the vicinity of the capacitor.
5. If the board contains multiple faults, the highest magnitude ratio difference is obvious. This suggests a stepwise correction of faults: scan and repair the most obvious, scan and repair the new most obvious, etc.

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|---|---|---|

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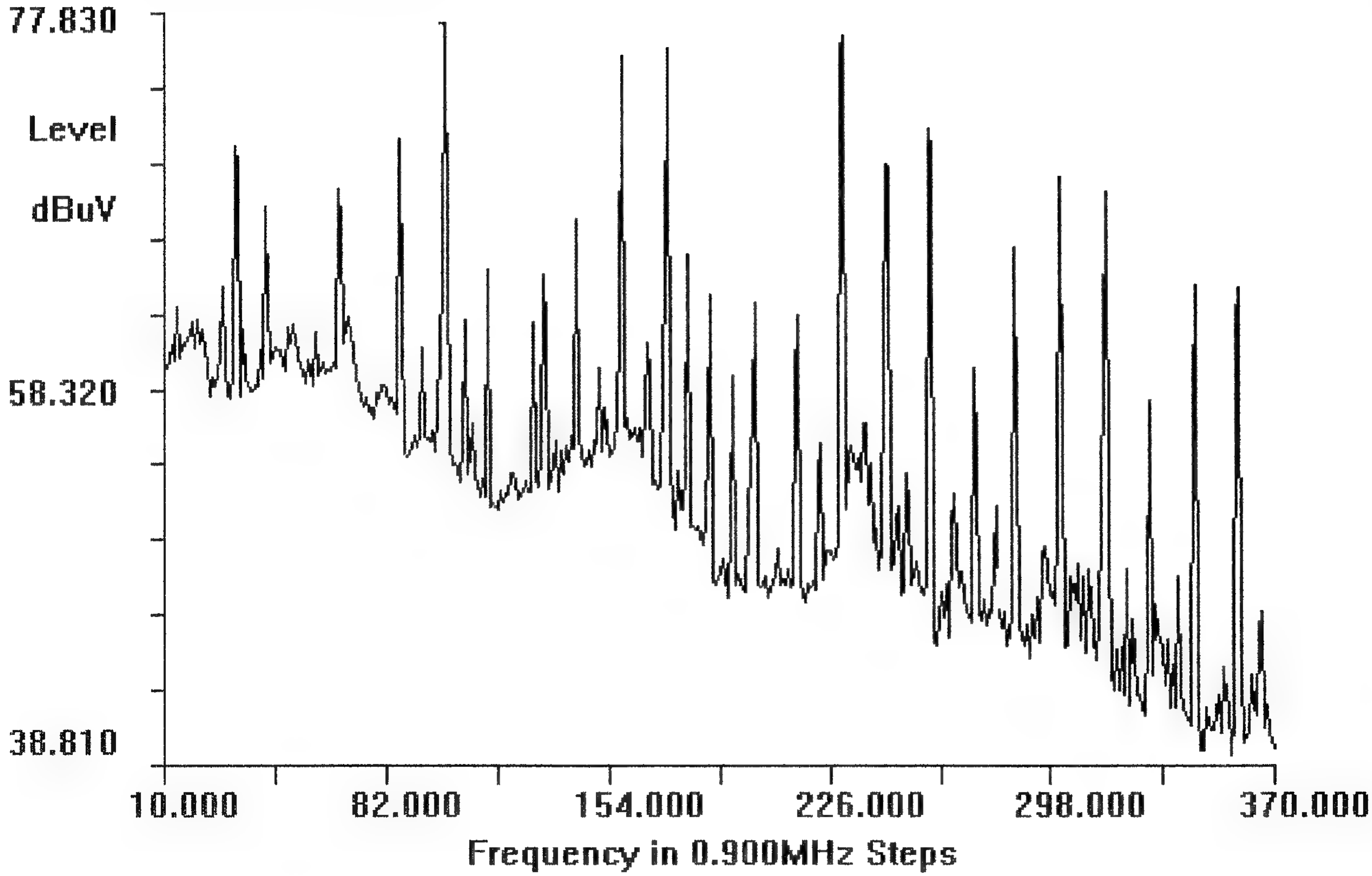
SPECTRAL

Scan A



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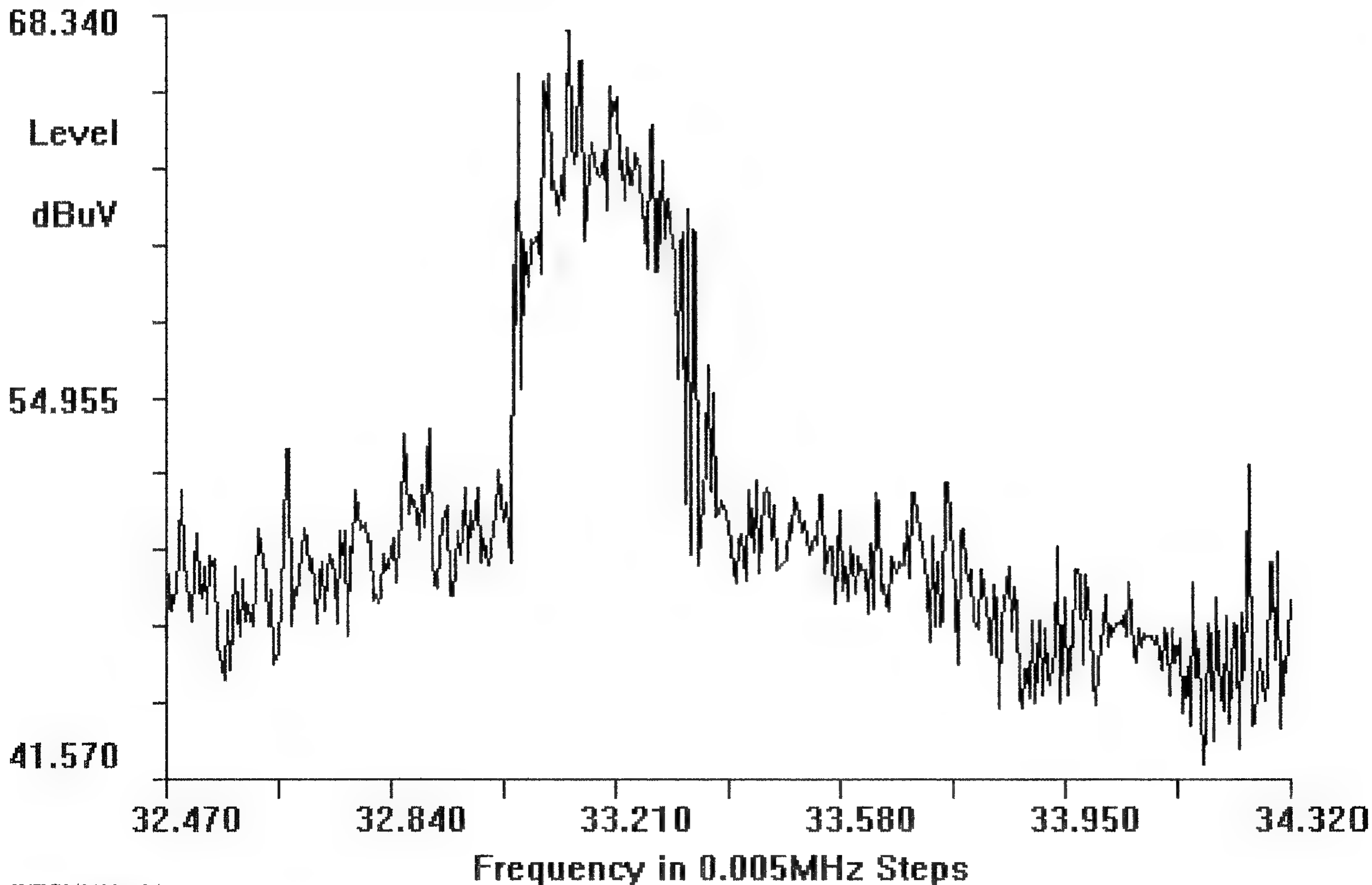
SPECTRAL
Scan A




WTC3/21Nov94

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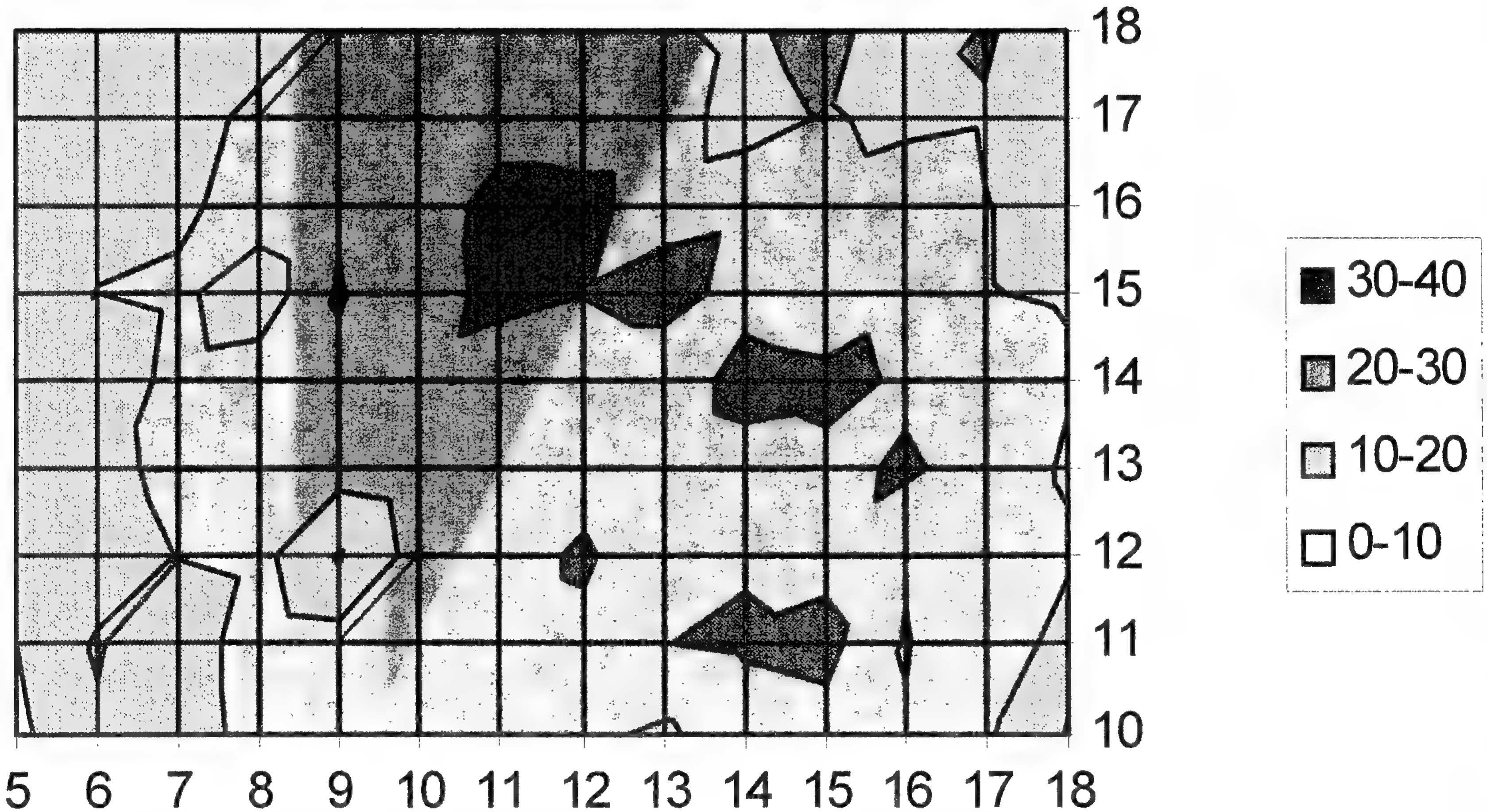

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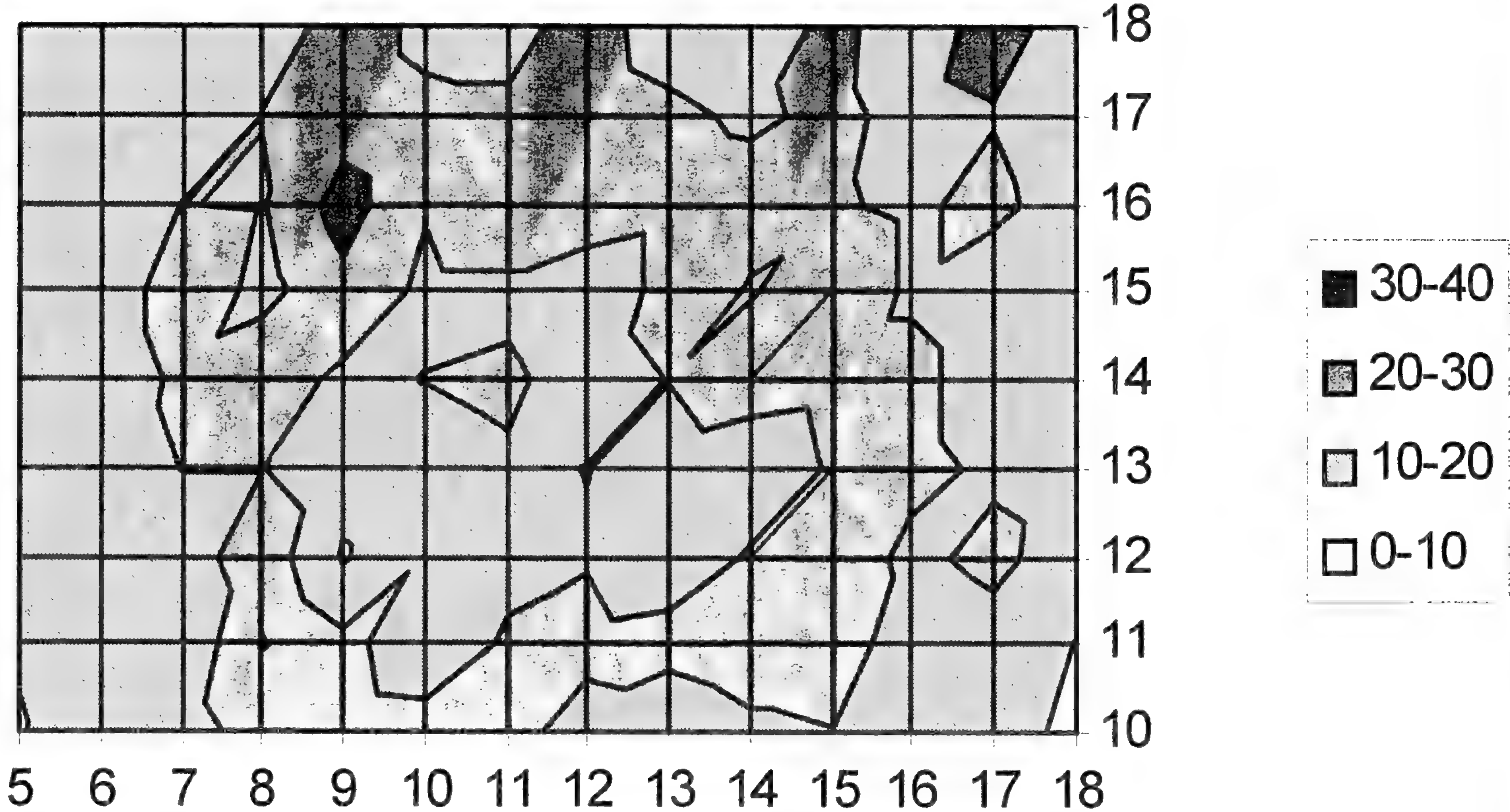

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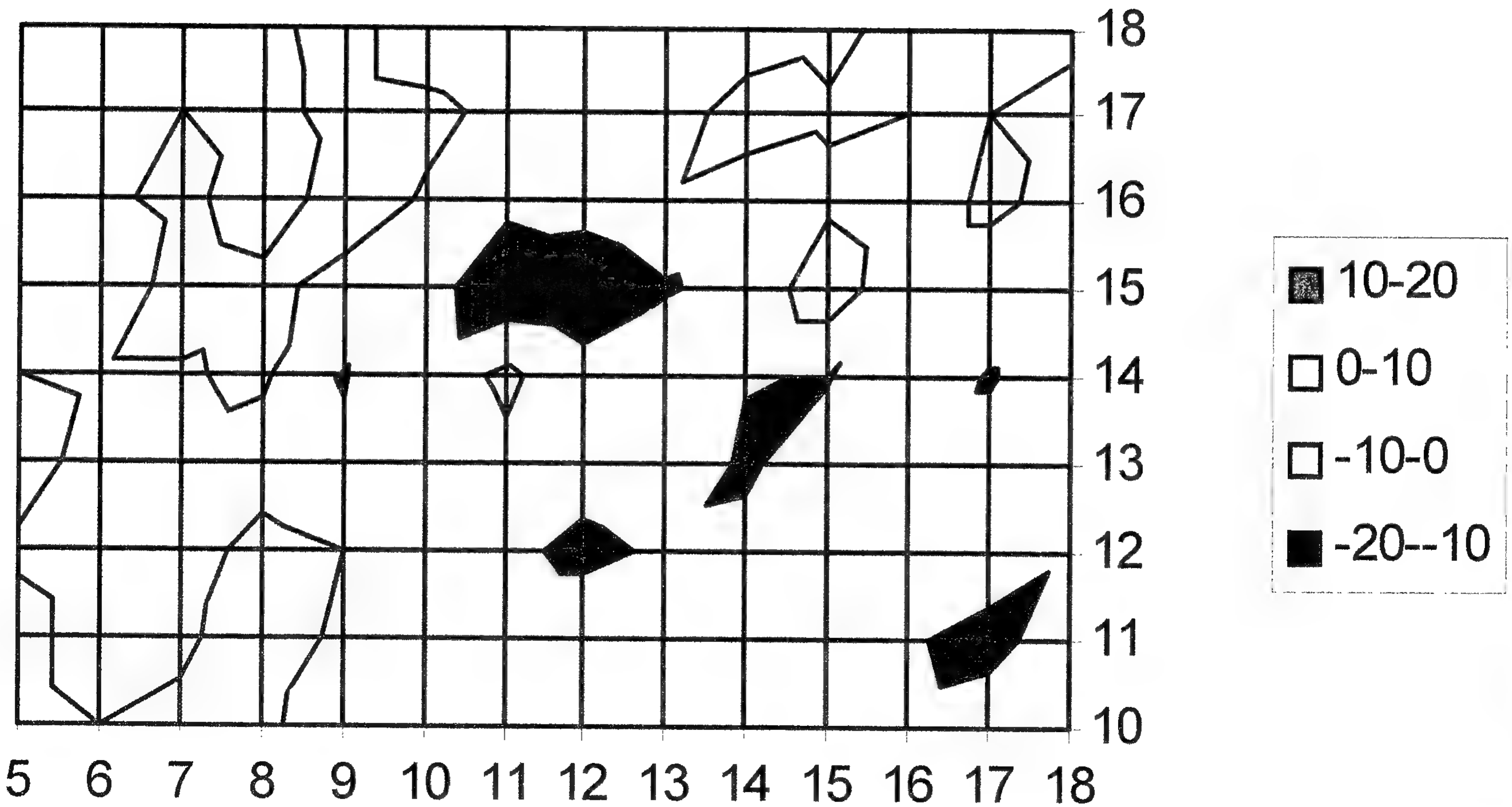

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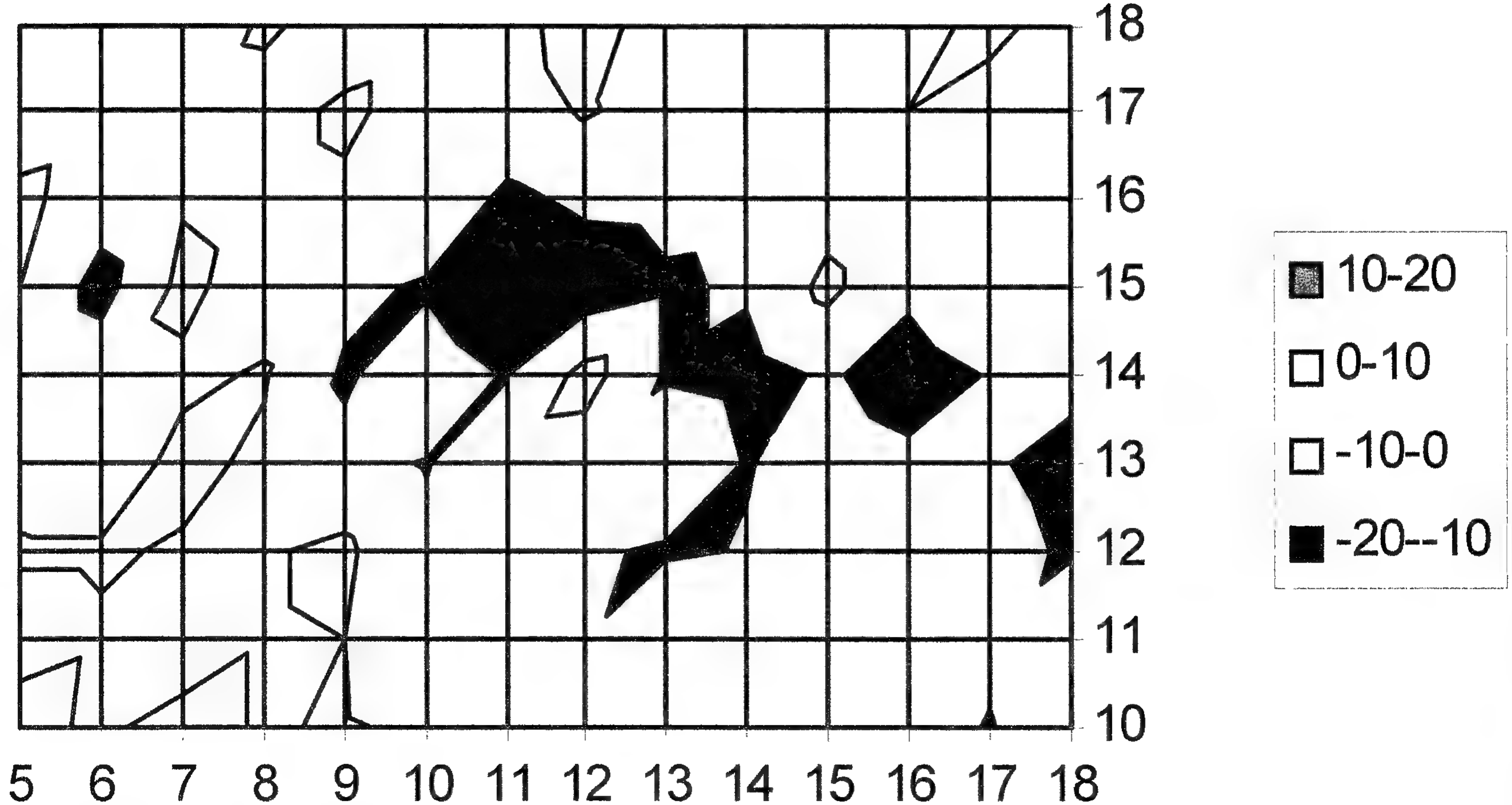

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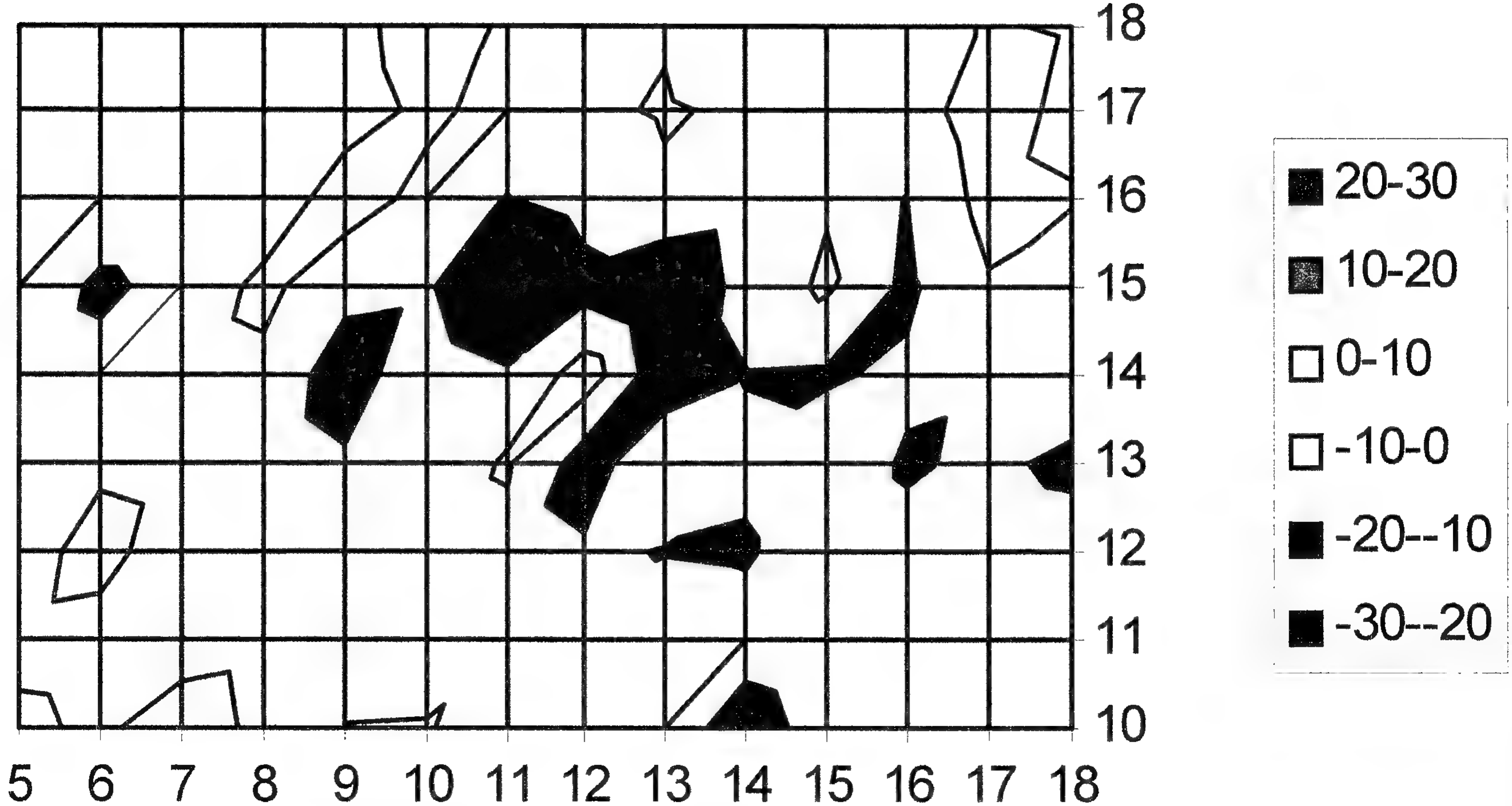

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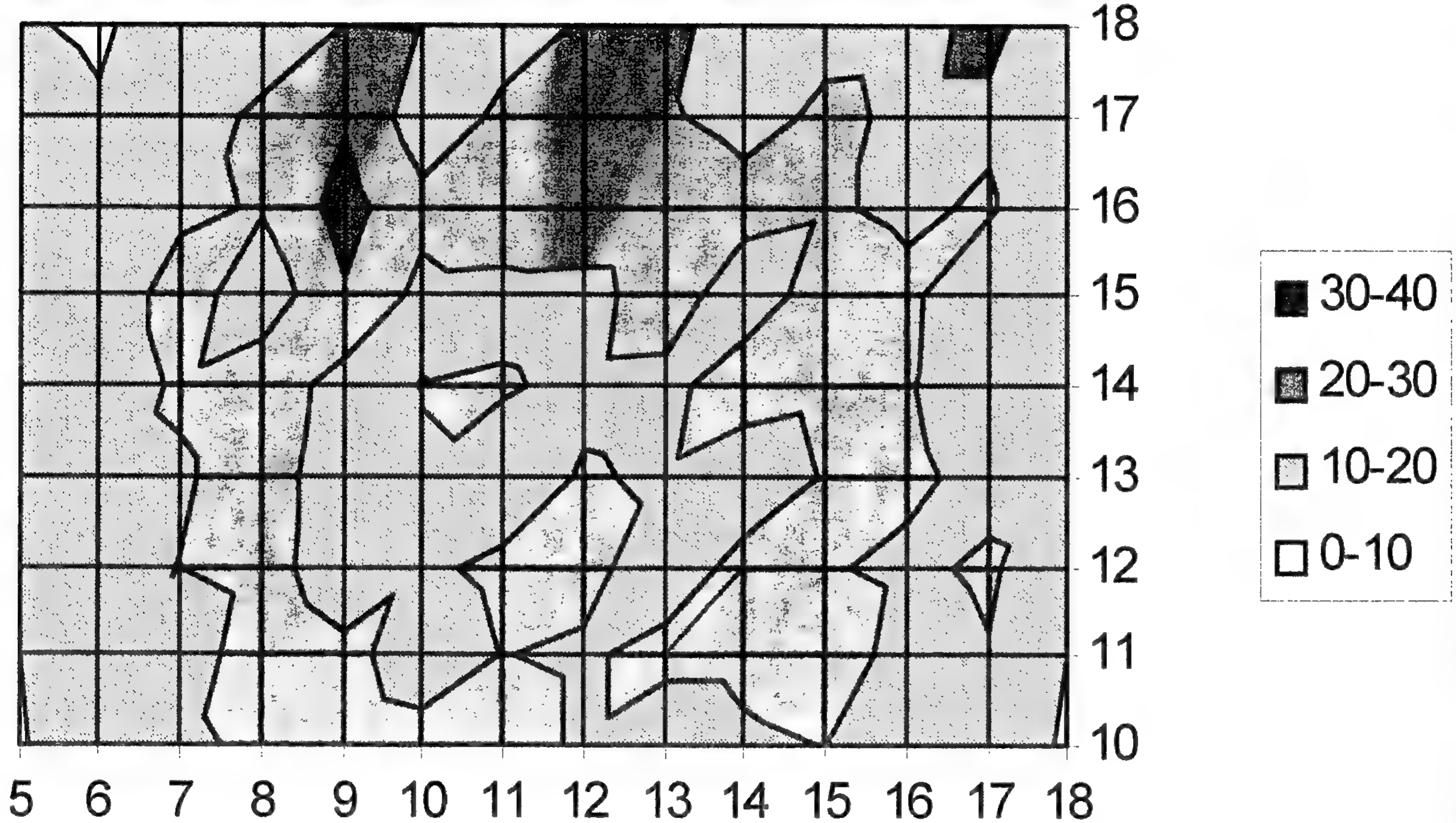

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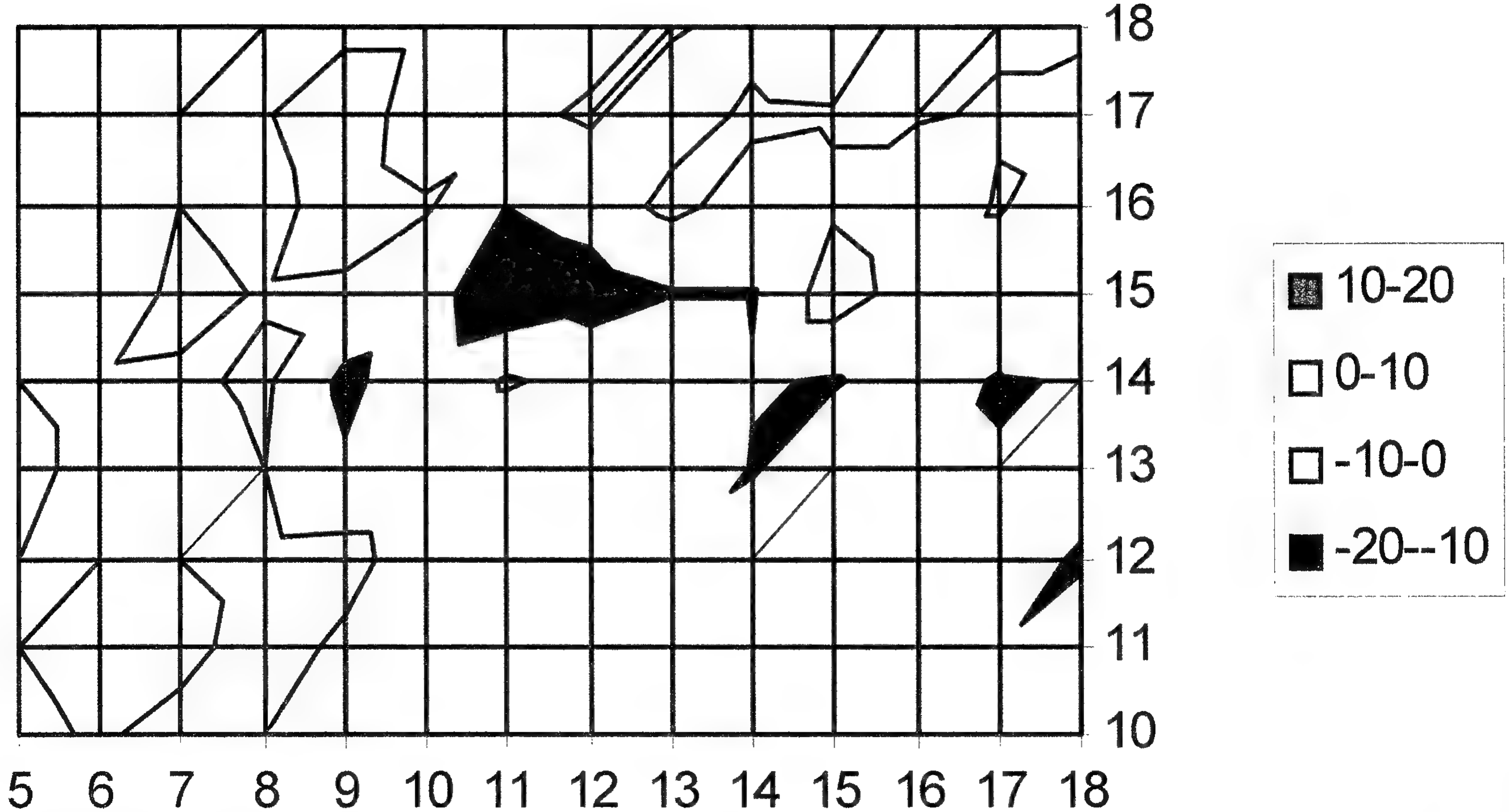

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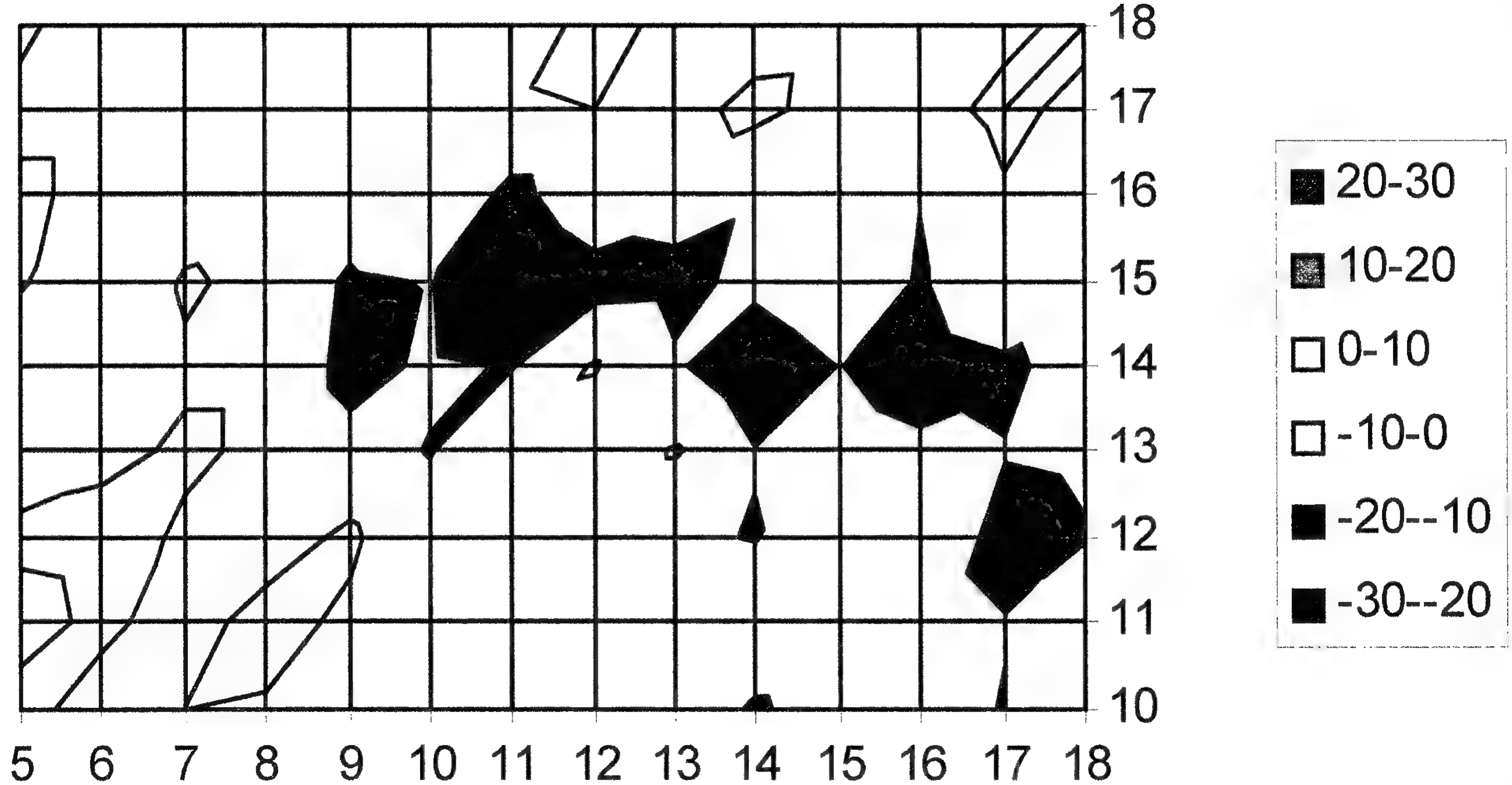

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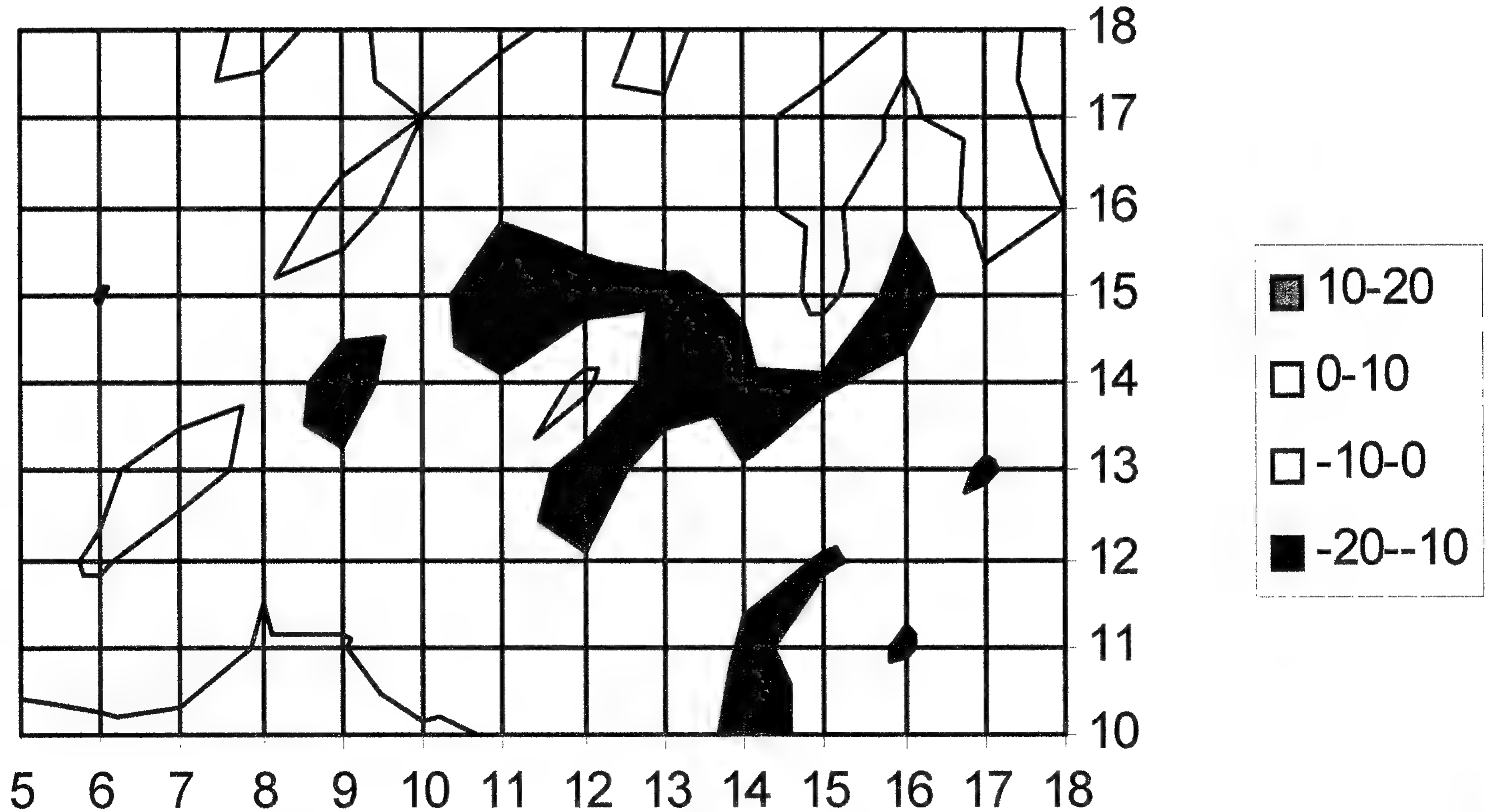

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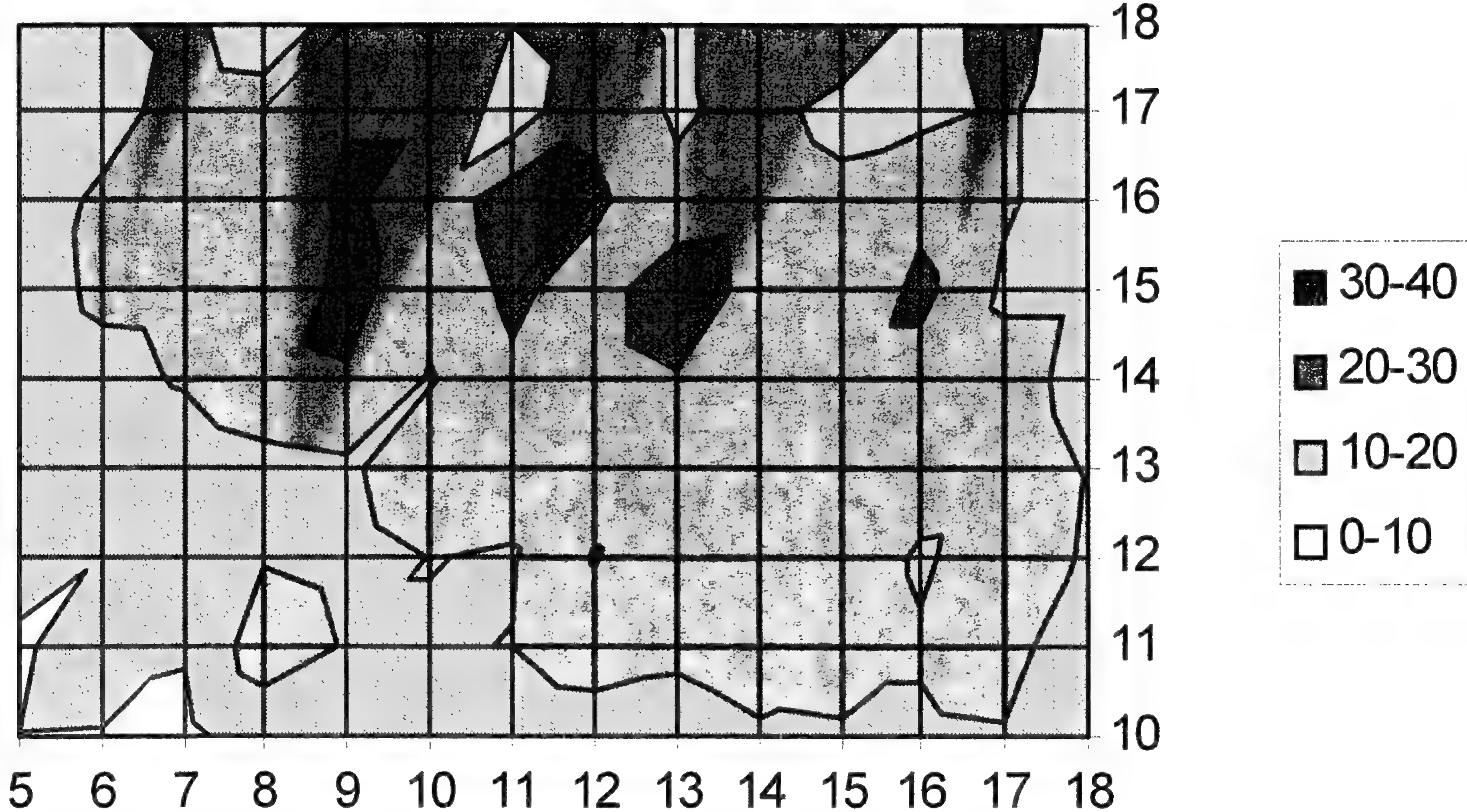

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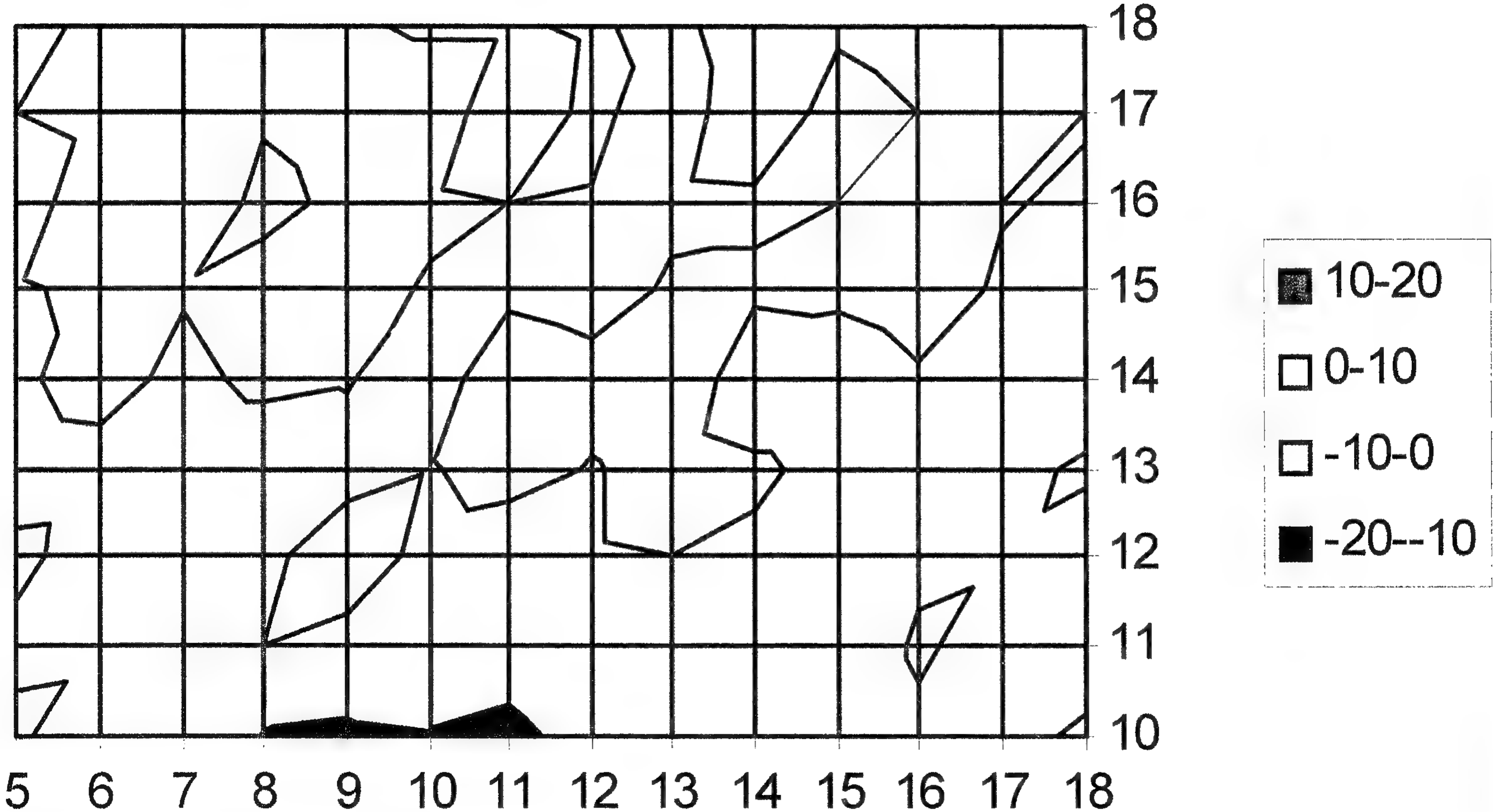

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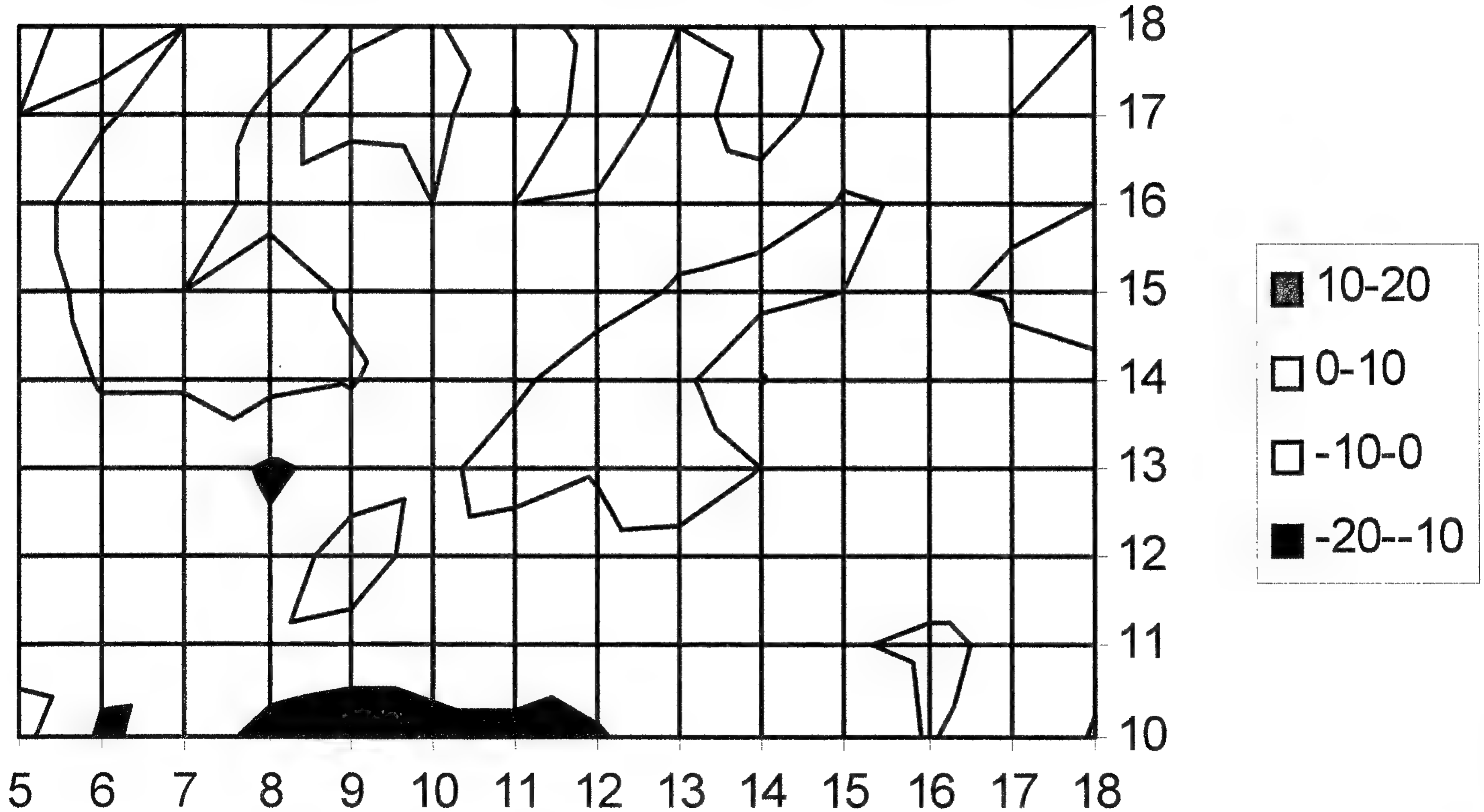

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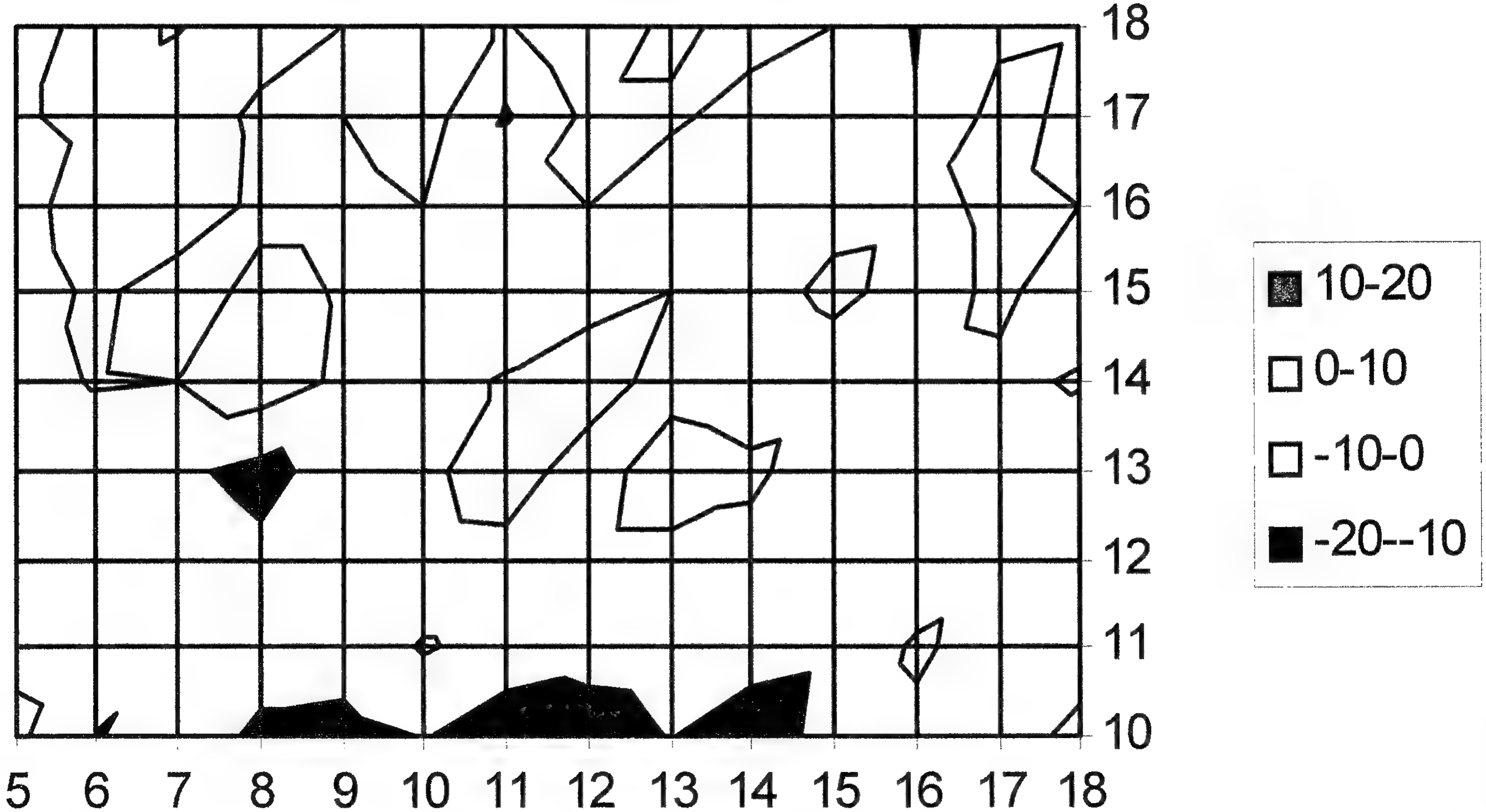

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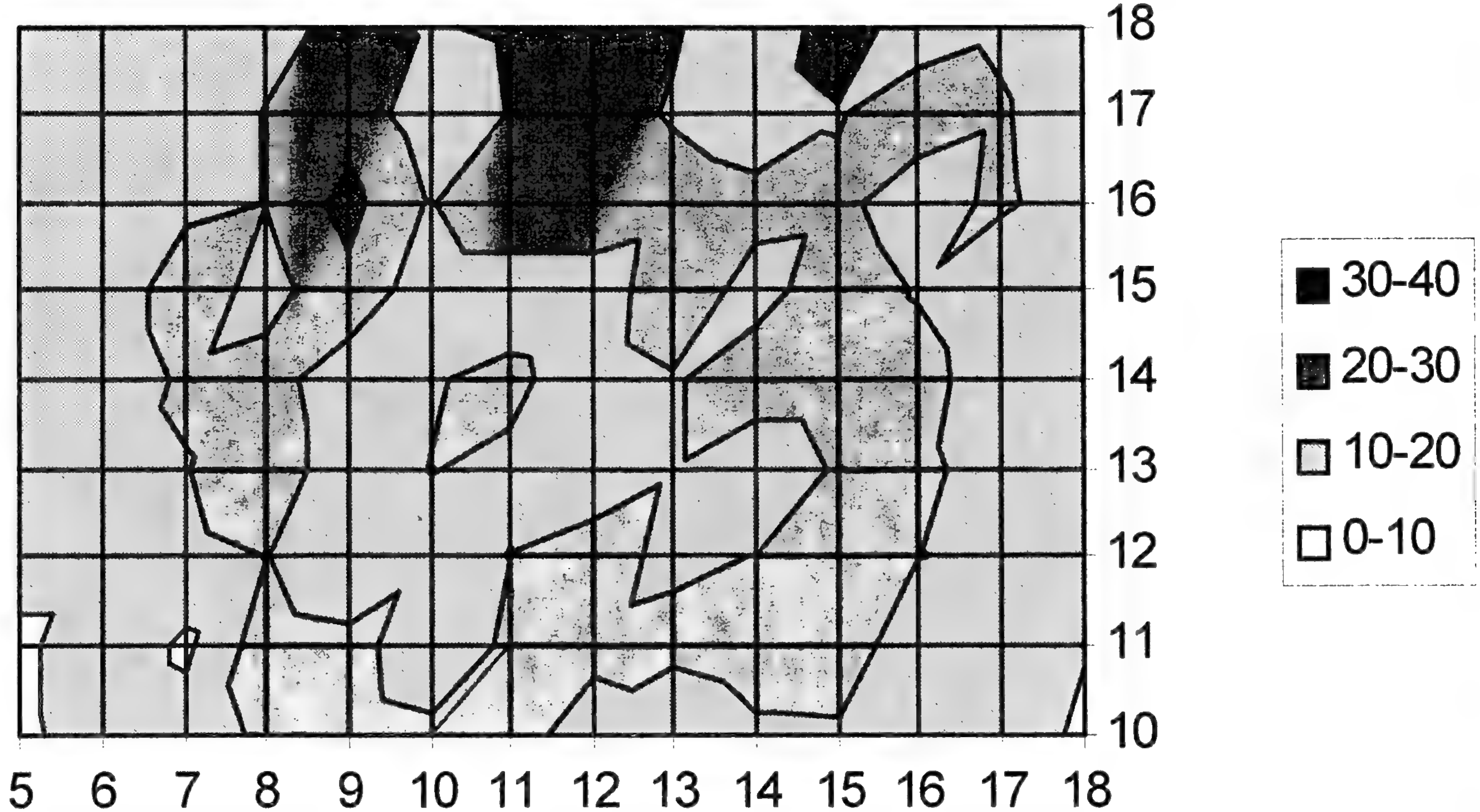
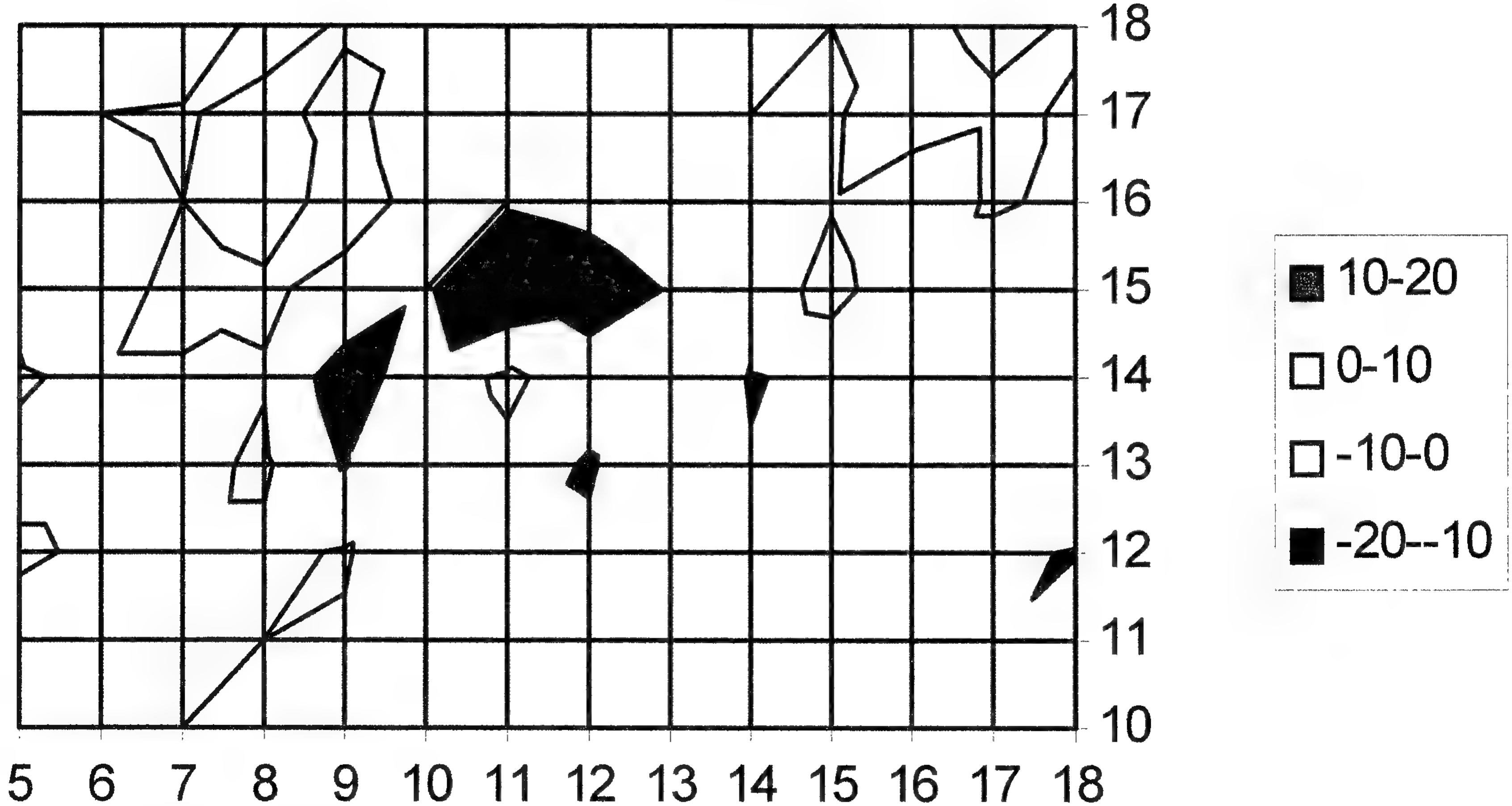
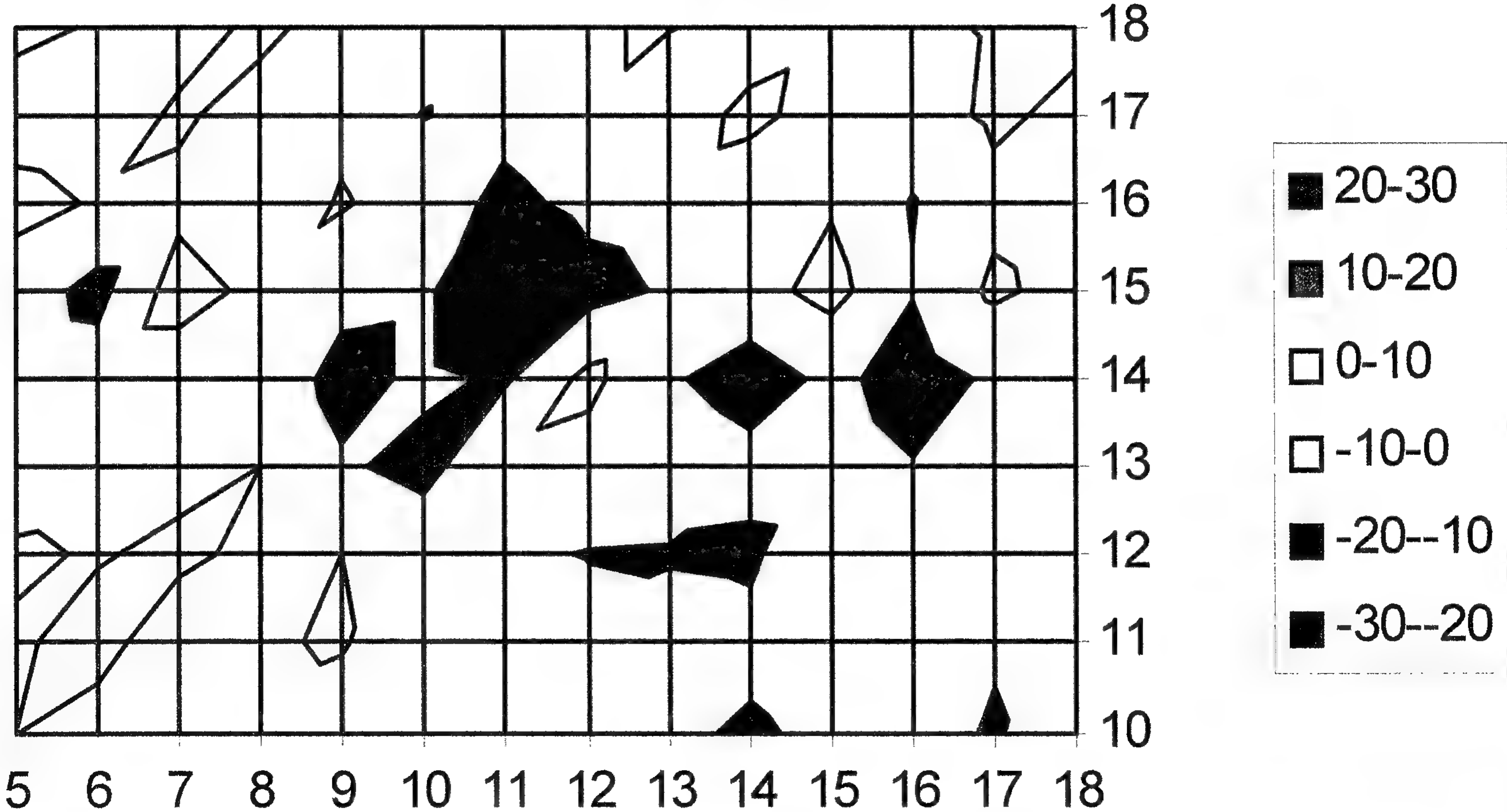


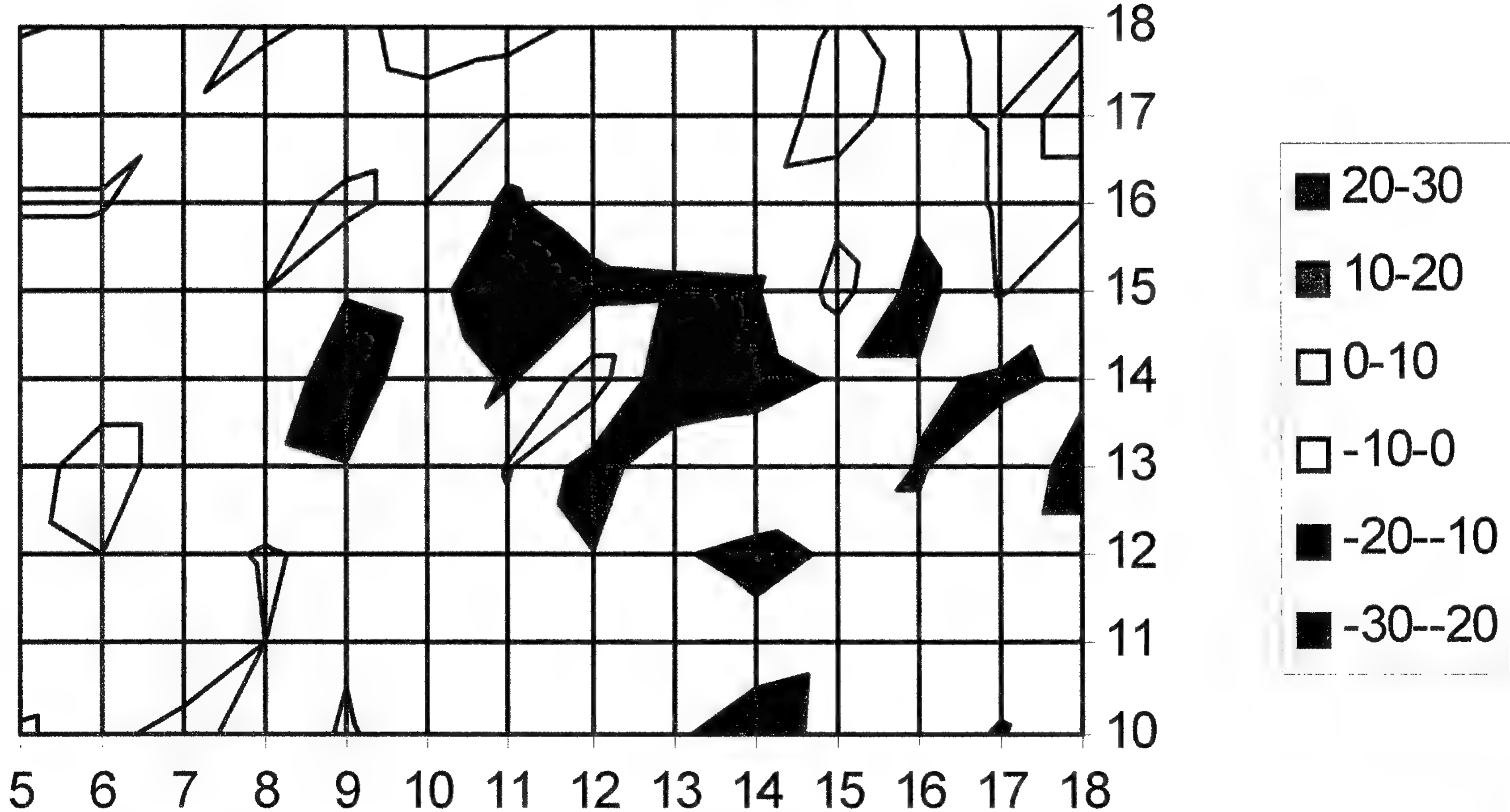
# OPEN@U4&SHORT@C12/NORMAL: 34.19 MHZ



# OPEN@U4&SHORT@C12/NORMAL:
# 34.23 MHZ



# OPEN@U4&SHORT@C12/NORMAL: 34.30 MHZ



## Contents

# APPENDIX 2

## Printer Card Analysis (Ancillary)

It is suggested that the reader review the slides presented in Appendix 1 prior to assessing this data. That will provide an aid in characteristic identification and pattern recognition. All slides are of parallel printer cards for the personal computer powered via an umbilical from a PC.

A majority of the slides presented in November were spatial scan ratios at three frequencies: 30.19 MHz, 30.23 MHz and 30.30 MHz. This set of slides contains only spatial scan ratios: the particular condition scan over the normal scan. All units are dB. Only the three previously mentioned frequencies are presented. The bandwidth for all scans was 10 hz. Eight conditions are discussed.

1. Ratio of two spatial scans: Print Card B / Print Card A: frequency = 34.23 MHz, bandwidth = 10 Hz. (A slide for F = 34.19 MHz is not shown as the largest magnitude difference was less than 10 dB.) The two blue areas indicate a 10 to 20 dB signal difference between the cards, yet both areas are quite small compared to shorted or opened components. (Even though the circuit cards tested were manufactured in the same lot, they do not contain identical components (eg from the same chip manufacturer. The U2 integrated circuit chip (1 of 4 on the board) is different on each board. U2 lies along rows 14 and 15, from column 14 to 16.)

2. Print Card B / Print Card A: frequency = 34.30 MHz. A differential is observed, yet of low absolute magnitude in isolated areas.

   - A spatial scan ratio difference is observed between similar circuit cards. Different components are observed, yet the difference is not of the magnitude nor the area of shorts, opens or partially powered circuits.

3. 25% Power to U4 / Normal: frequency = 34.19 MHz. The large differential magnitude area along row 15 is the location of integrated circuit U4.

4. 25% Power to U4 / Normal: frequency = 34.23 MHz. A differential magnitude greater than 20 dB is observed at integrated circuit U4.

5. 25% Power to U4 / Normal: frequency = 34.30 MHz. Again , U4 is seen to exhibit signal differential.

   - An integrated circuit powered at 25% normal is easily observed.

6. 50% Power to U4 / Normal: frequency = 34.19 MHz. U4 emits a signal of larger area than the 25%/normal ratio.

7. 50% Power to U4 / Normal: frequency = 34.23 MHz. U4 emits a signal of larger area than the 25%/normal ratio.

8. 50% Power to U4 / Normal: frequency = 34.30 MHz. U4 emits a signal of larger area than the 25%/normal ratio.

- The larger area signature (as compared to the 25%/normal slides) may be indicative of a threshold level reached in U4 between 25% and 50% power.

9. 75% Power to U4 / Normal: frequency = 34.19 MHz. A small signal, in both amplitude and power, is seen to emanate from U4. Apparently, 75% power is sufficiently more "normal" than 50% power to not generate a larger cool ratio area. Of greater note are the several hot ratio amplitude areas observed. Perhaps the power intended to supply U4 from the PC is effecting other portions of the card.

10. 75% Power to U4 / Normal: frequency = 34.23 MHz. U4 emits a small magnitude and area signal.

11. 75% Power to U4 / Normal: frequency = 34.30 MHz. U4 emits a small magnitude and area signal.

- The smaller area signature (as compared to either 25% or 50%/normal slides) may be characteristic of yet another threshold, one indicating sufficient operating power for U4.

12. 100% Power to U4 / Normal: frequency = 34.19 MHz. U4 emits a signal.

13. 100% Power to U4 / Normal: frequency = 34.23 MHz. U4 emits a signal.

14. 100% Power to U4 / Normal: frequency = 34.30 MHz. U4 emits a signal. Study of these independent partial power to U4/normal slides shows a pattern. The difference may be due to power intended to supply U4 from the PC not reaching U4, which is sufficiently powered, and effecting other portions of the card.

- A signature requiring further examination is observed. Acquisition of data with the partially power circuit obtaining power from the normal power source is indicated.

15. 25% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.23 MHz. (A slide for F = 34.19 MHz is not shown as the largest magnitude difference was less than 10 dB.) No significant differential is observed.

16. 25% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.30 MHz. No significant differential is observed.

- No large differences were observed, indicating small displacements of the circuit card on the EMSCAN unit may not generate large signal ratios.

17. 50% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.19 MHz. No significant differential is observed.

18. 50% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.23 MHz. A differential is observed at U2 - U3.

19. 50% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.30 MHz. The differential at U2 - U3 is clear.

- A medium displacement (<= 50% of one cell dimension) of the circuit board generates a measurable differential signal.

20. 75% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.19 MHz Differentials are observed at U4 (11,15), U2 - U3 (15,14) and the switches (14,10).

21. 75% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.23 MHz. Differentials are observed at U2 - U3 and the switches.

22. 75% shift (of 1 cell) of card, both down and right / Normal: frequency = 34.30 MHz. Differentials are observed at U2 - U3 and the switches.

- A small displacement (<= 25% of one cell dimension) of the circuit board may not be of obvious consequence for measurement, yet certainly a medium (<= ~~25~~ 50%) or large (<= 75%) displacement is of consequence. Clearly, signals are emitted from ~~desecrate~~ circuit board components and captured by individual transducers within the EMSCAN. Placement of the test board is critical.

Conclusions:

1. Dissimilar components on similar circuit cards are observed, yet the difference is not of the magnitude nor the area of shorts, opens or partially powered circuits.

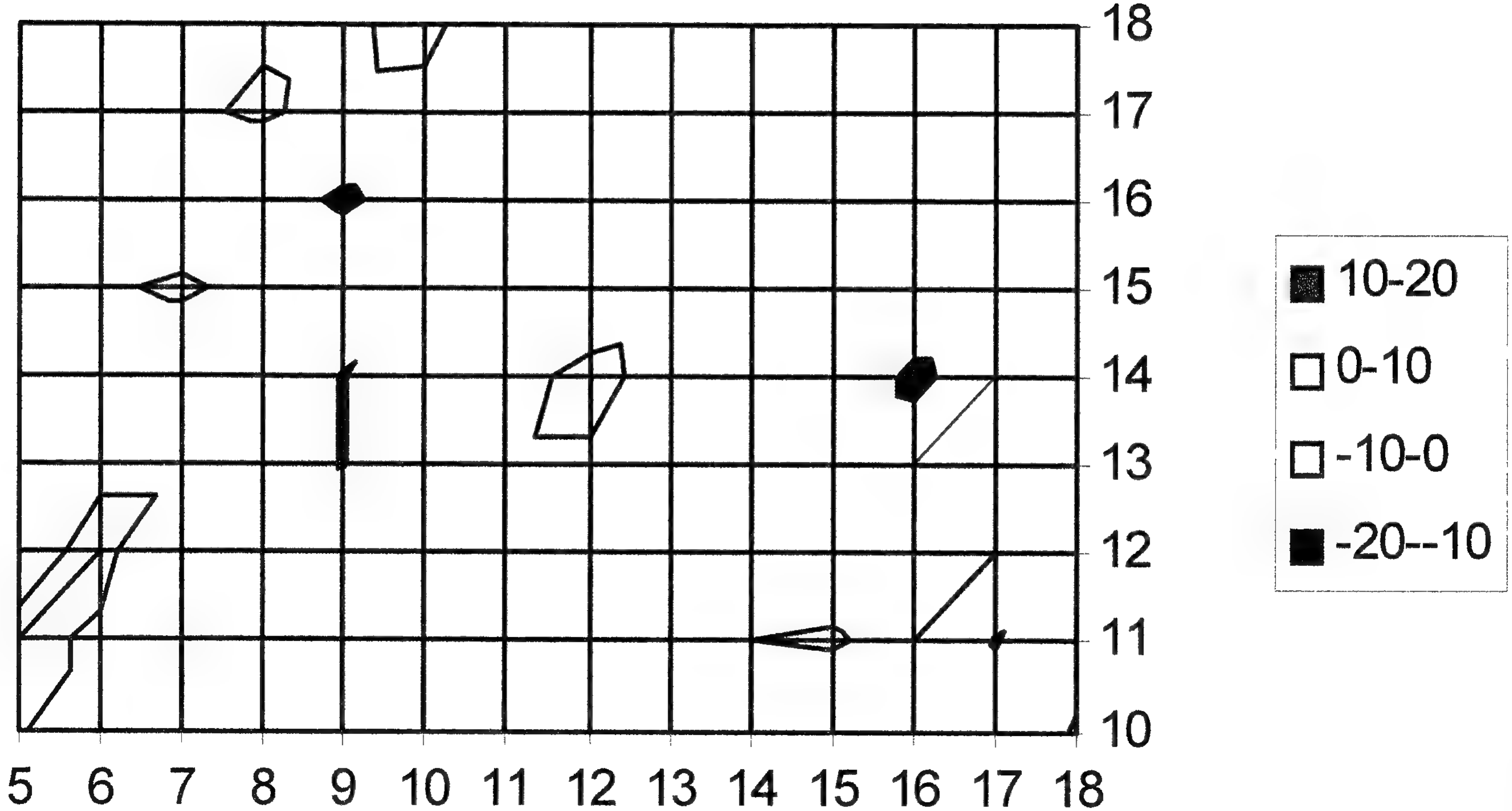
2. An under powered integrated circuit is easily observed.

3. Under (and over?) powered circuits may require power from their normal power supply, not an outside source.

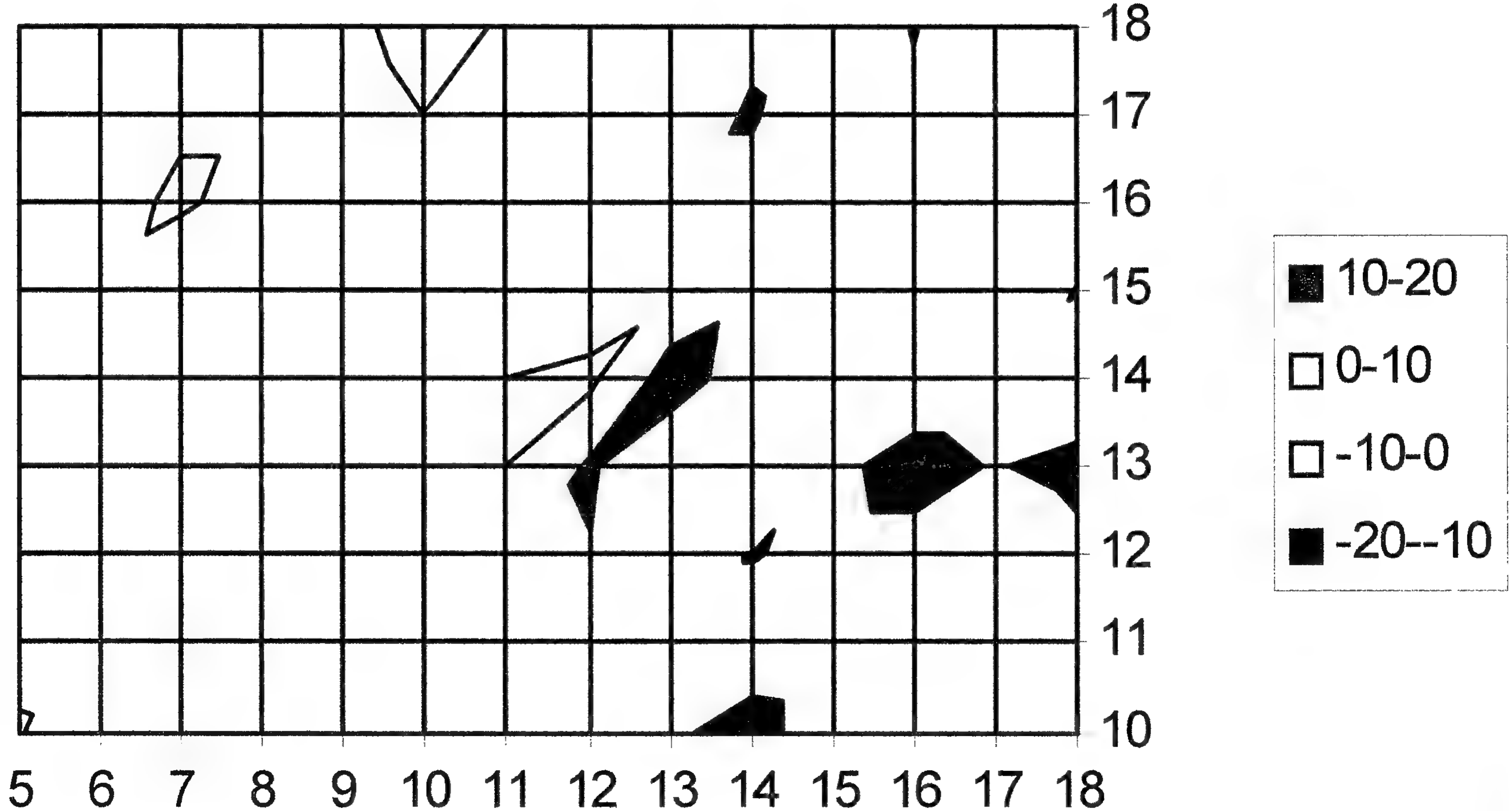
4. Card displacement of >= 25% of one cell dimension will result in a measurable signal.

5. Signals are emitted from discrete circuit card components and captured by individual transducers within the EMSCAN. Placement to within < 25% of a transducer cell is critical.

# PrintCardB/PrintCardA: 34.23 MHZ



# PrintCardB/PrintCardA: 34.30 MHZ



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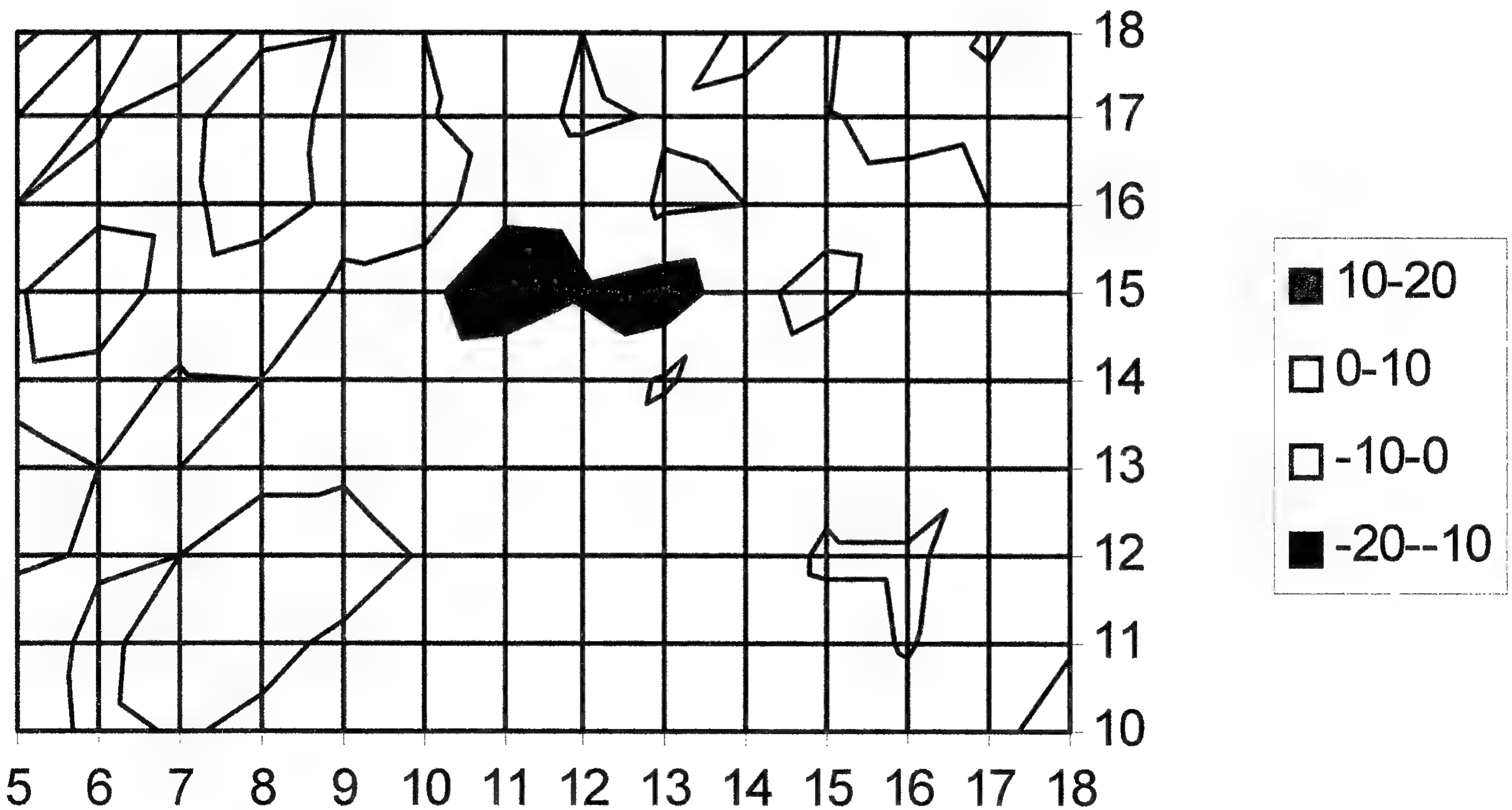

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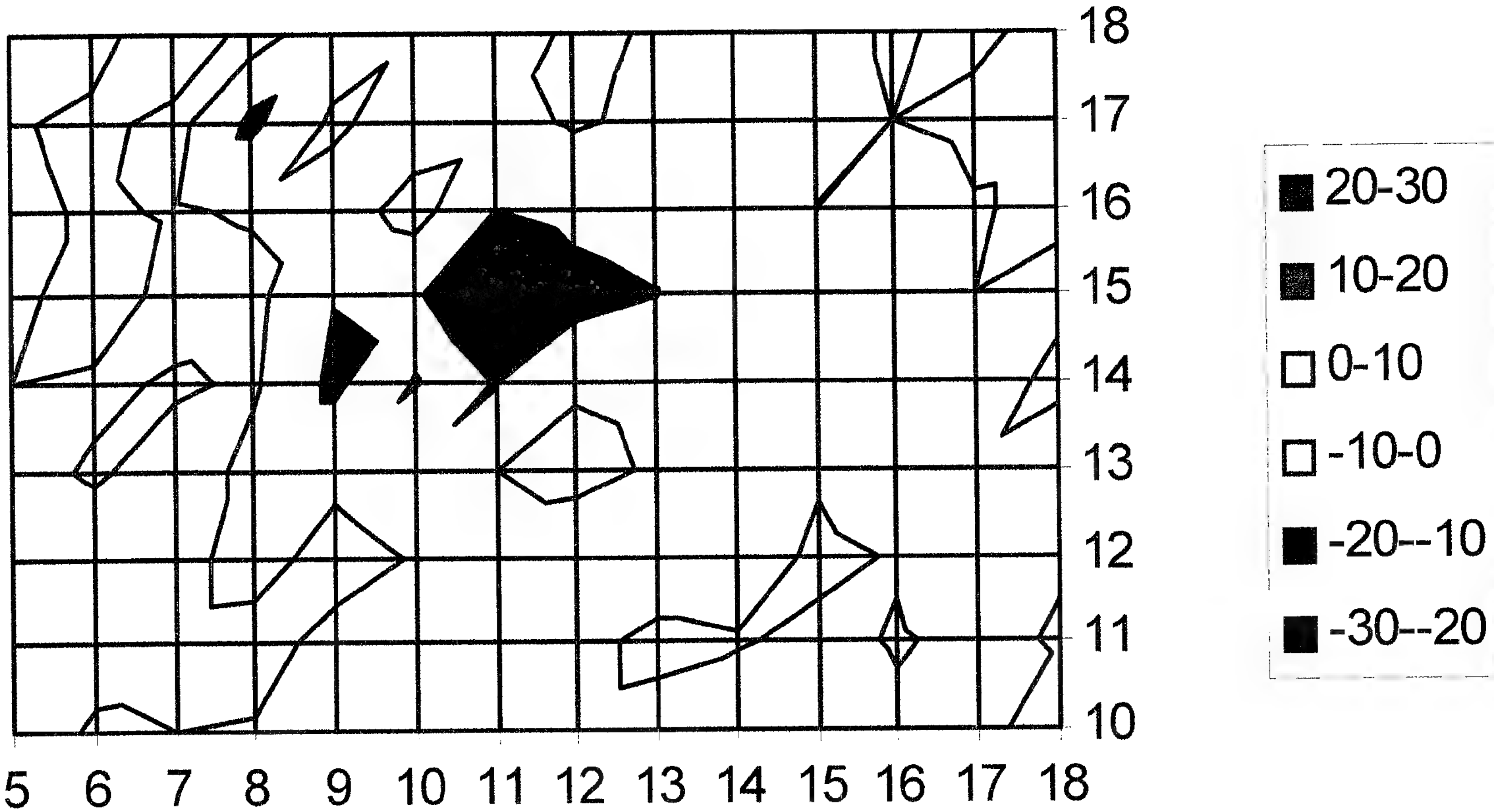
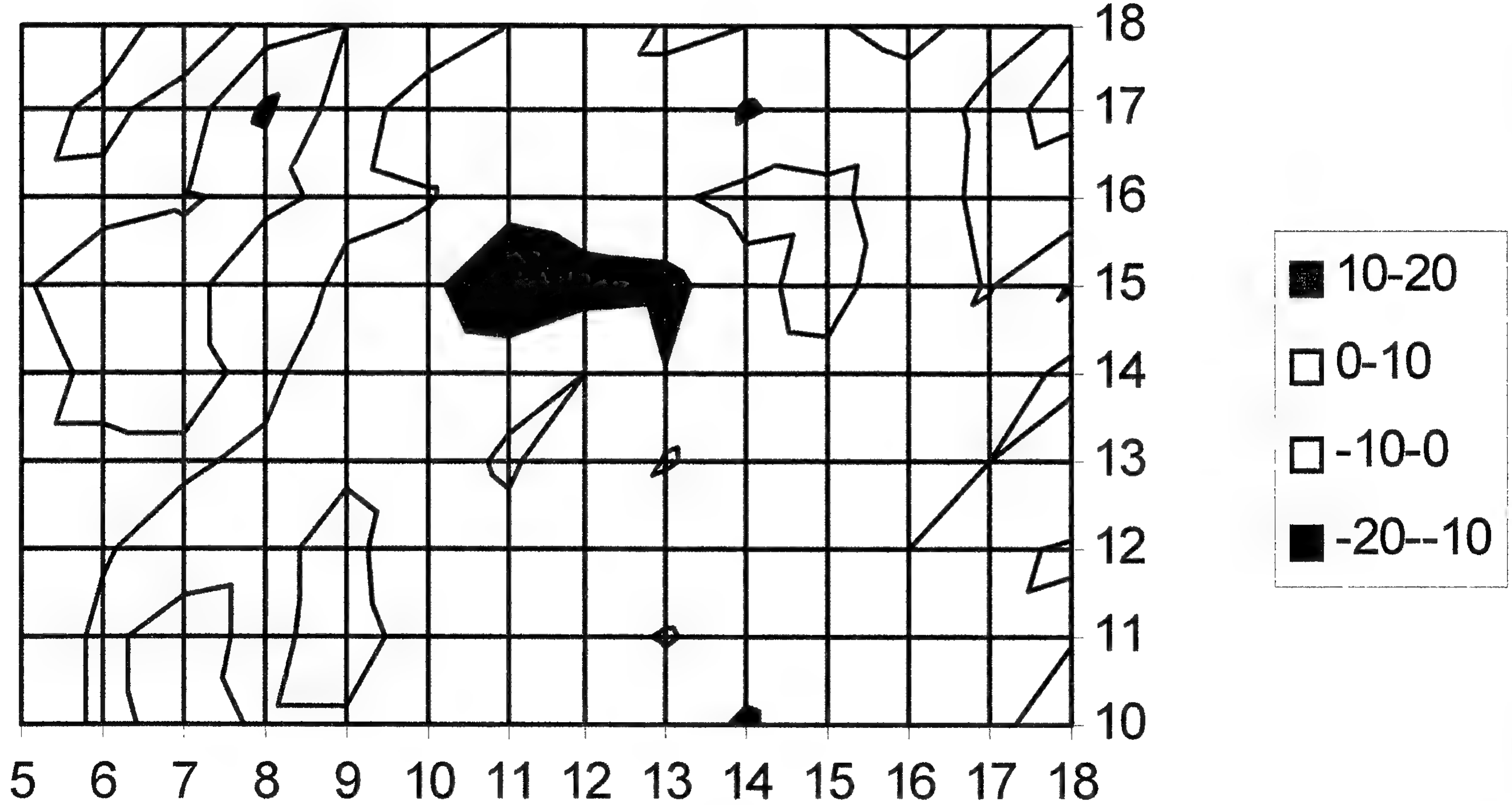


# 25%POWER@U4/NORMAL: 34.30 MHZ



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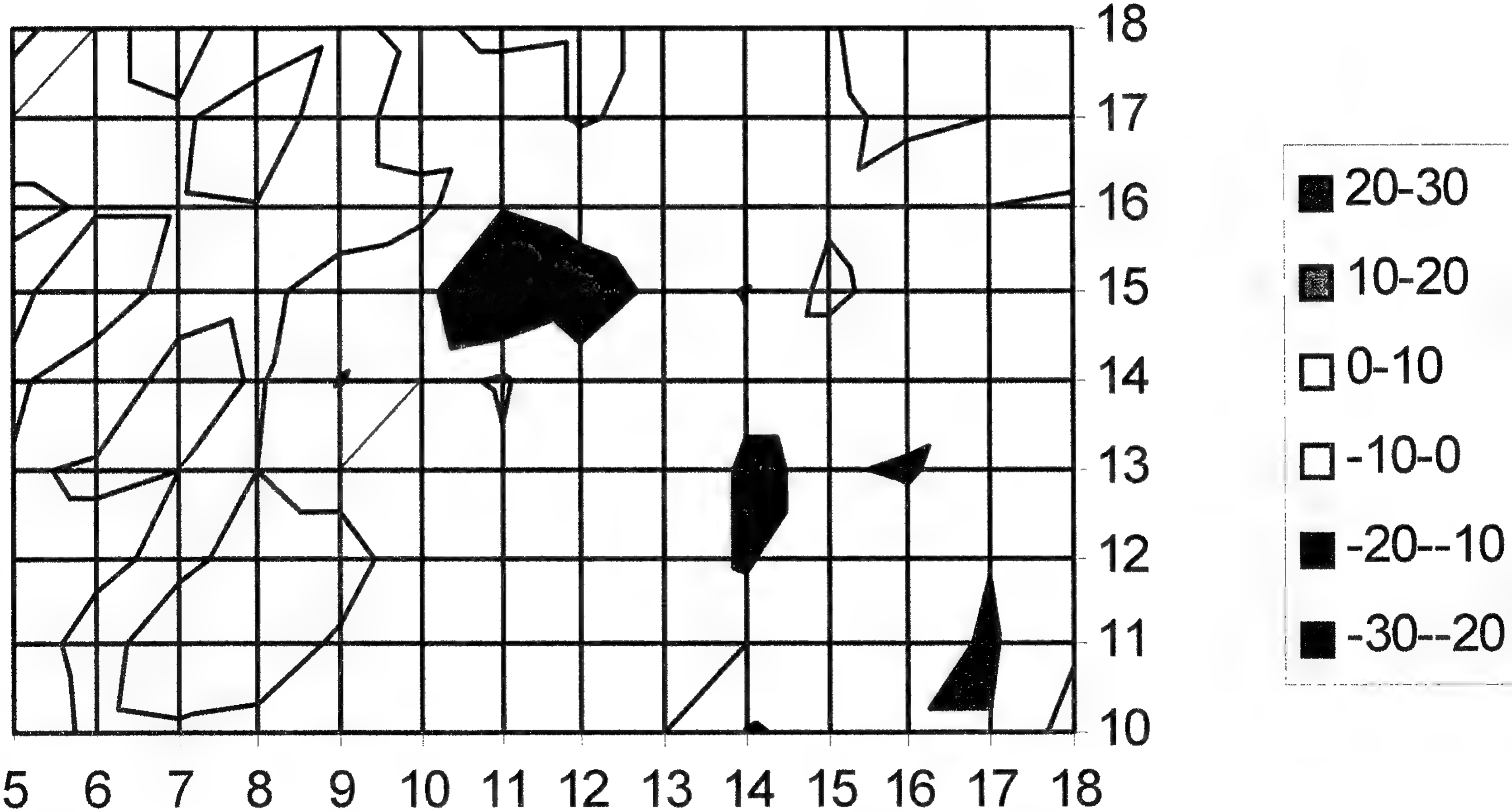
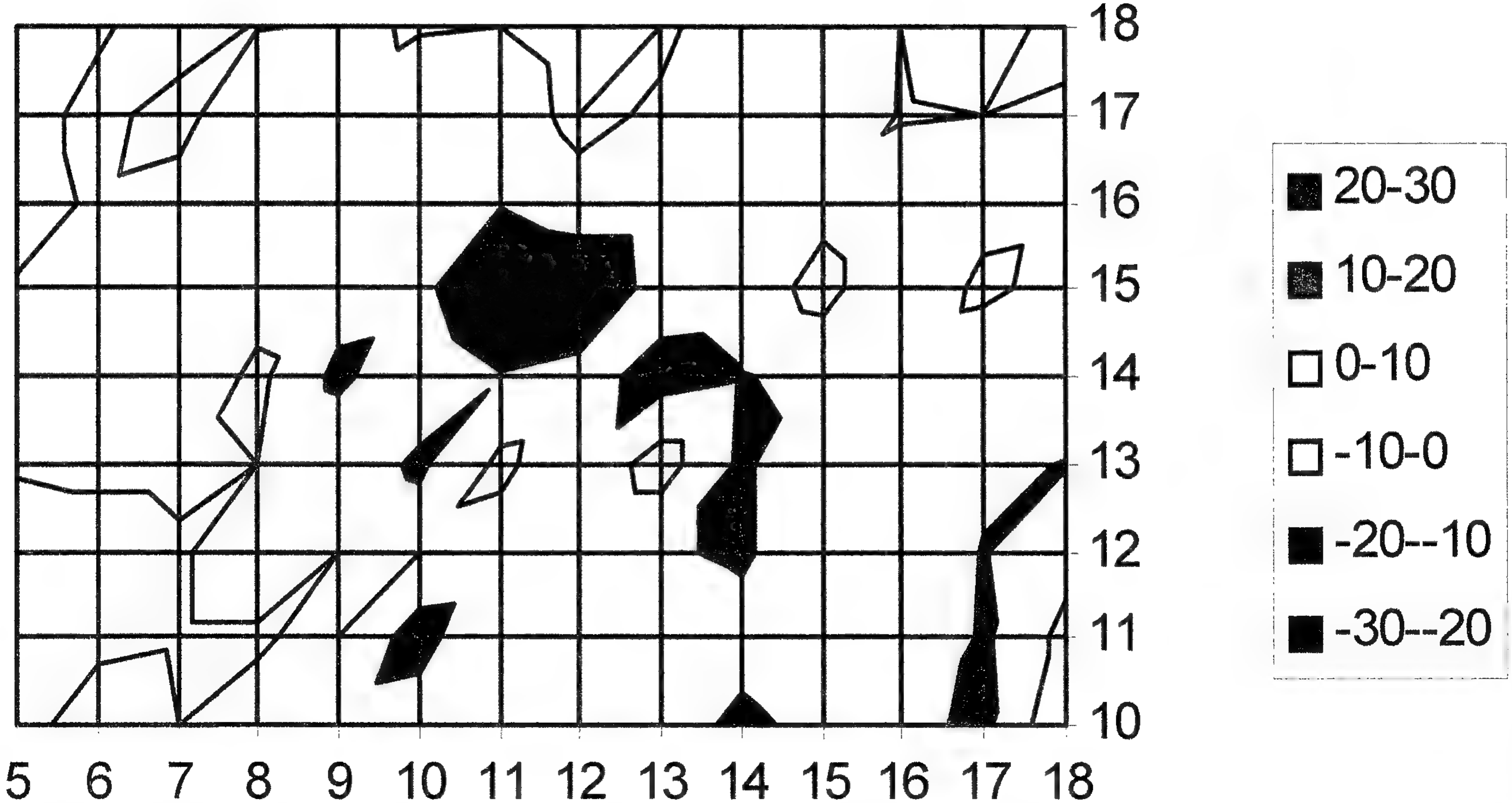
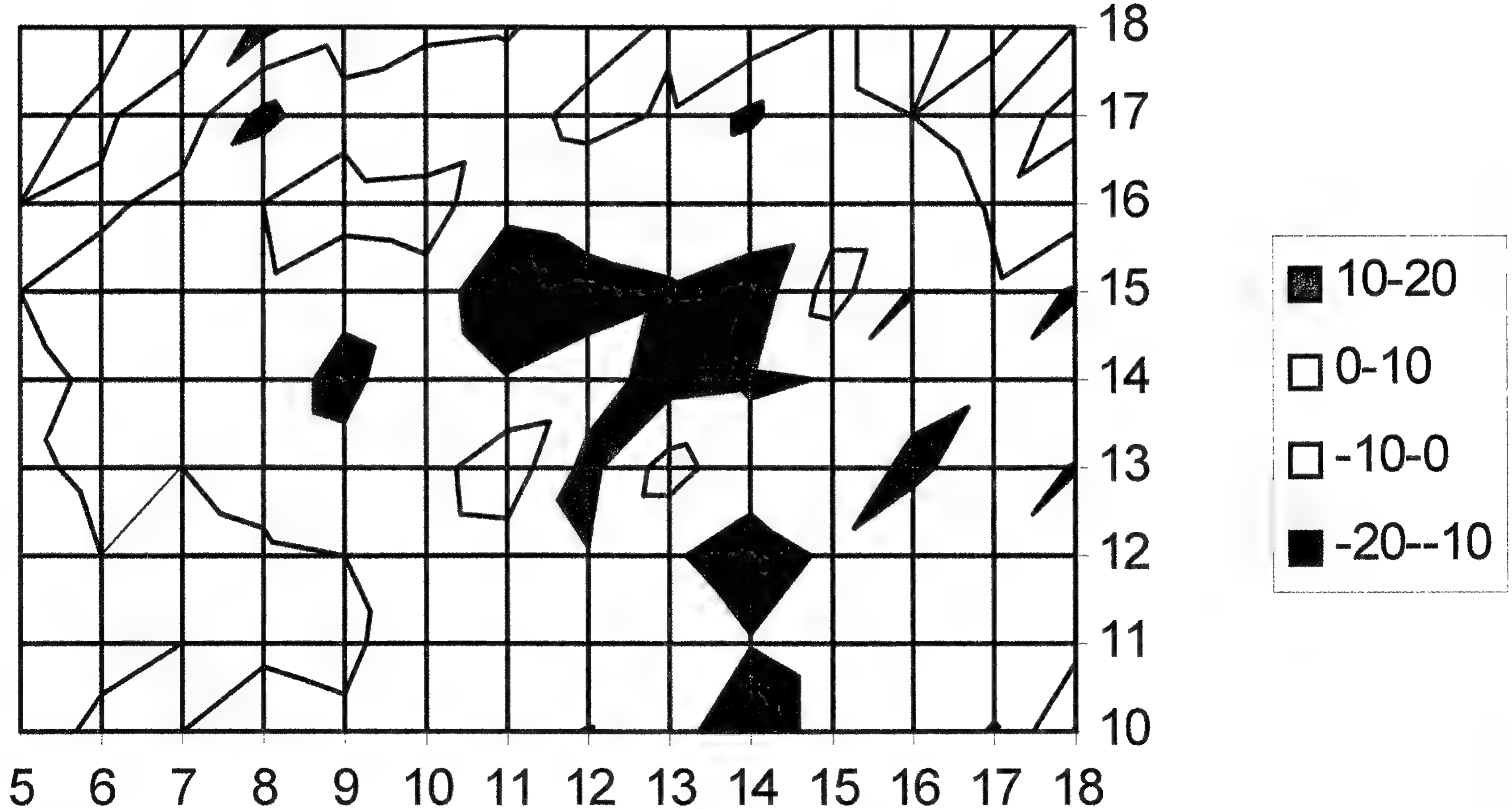


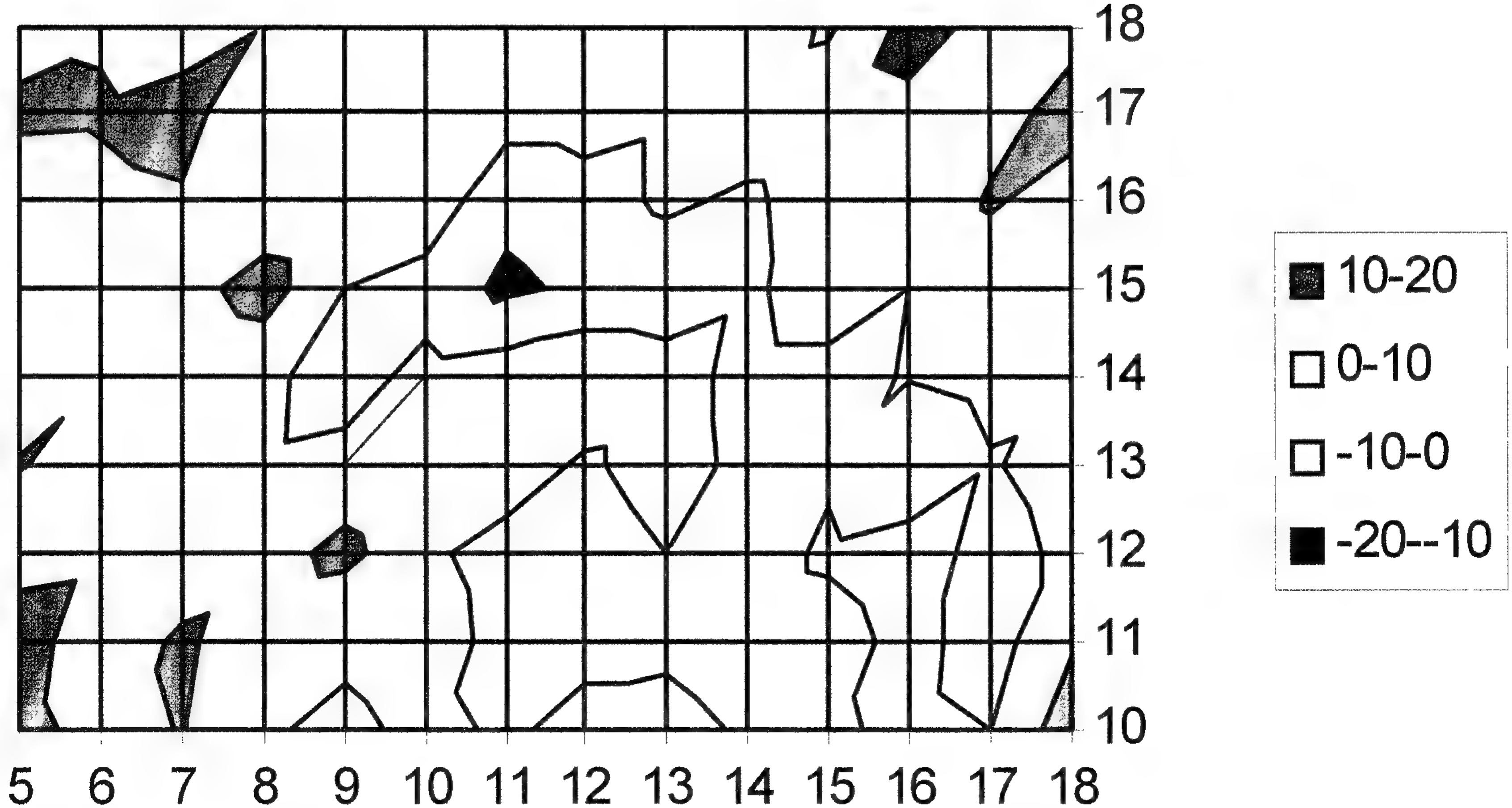
# 50%POWER@U4/NORMAL: 34.23 MHZ



# 50%POWER@U4/NORMAL: 34.30 MHZ



# 75%POWER@U4/NORMAL: 34.19 MHZ



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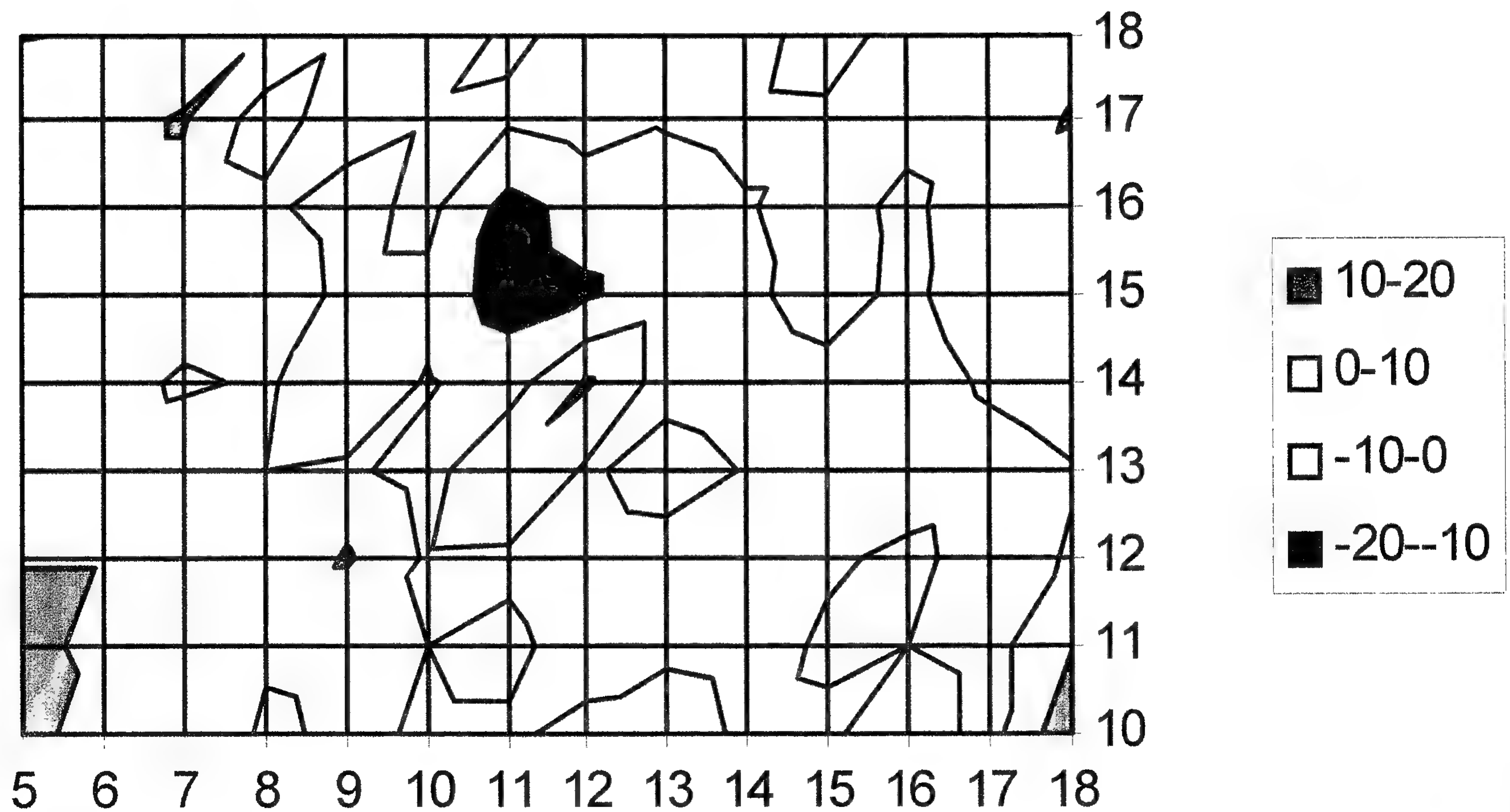

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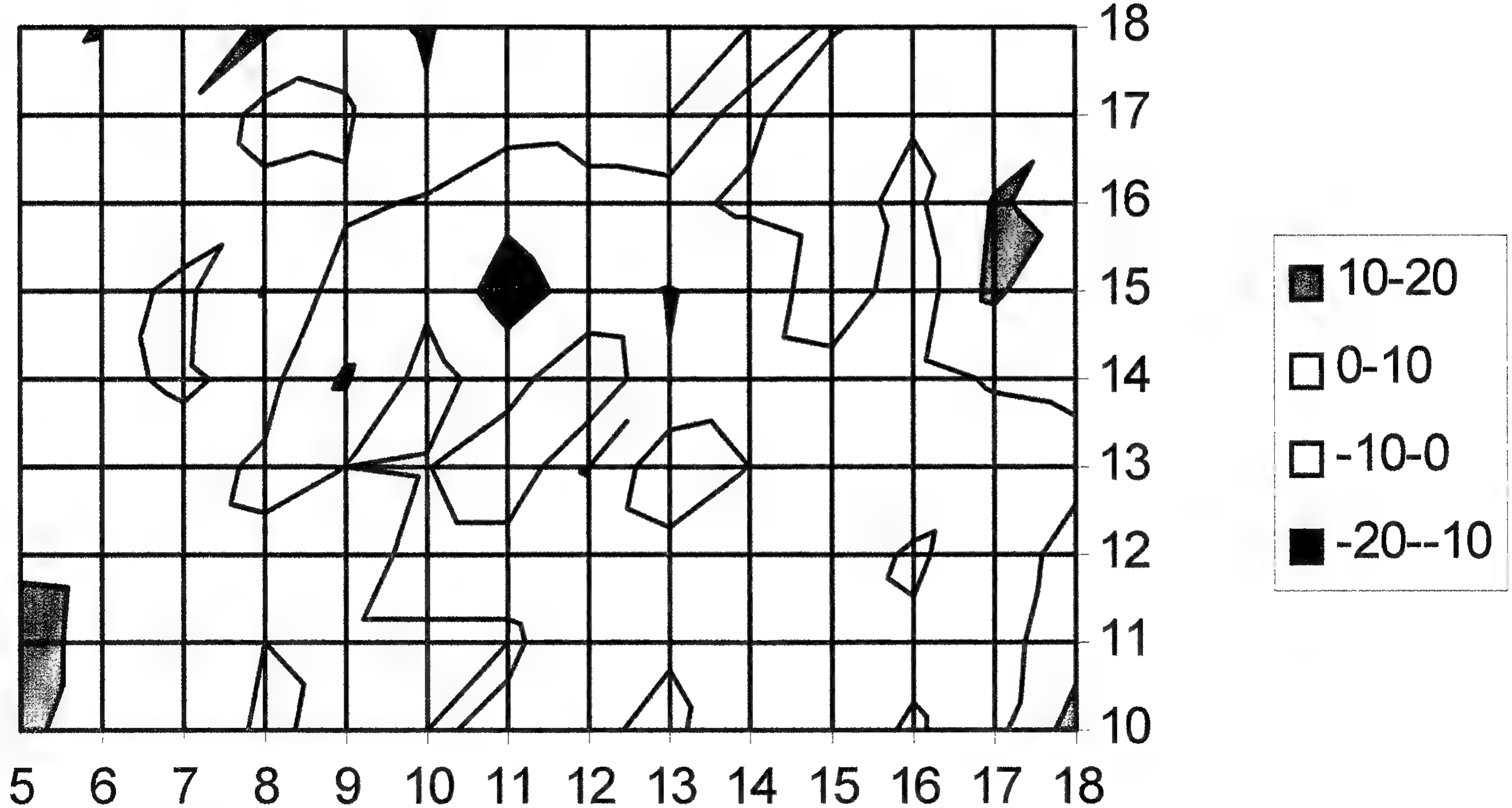

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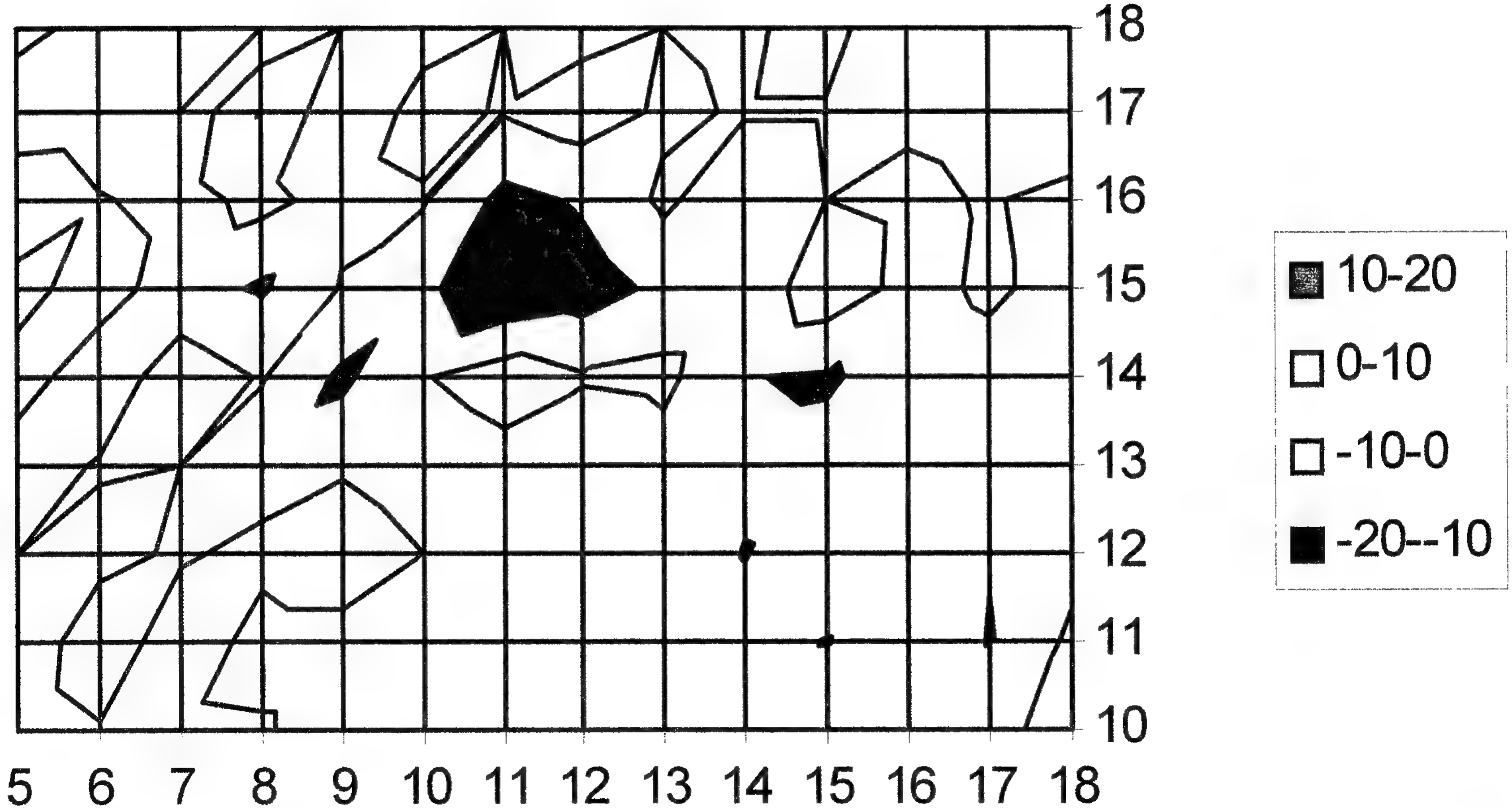

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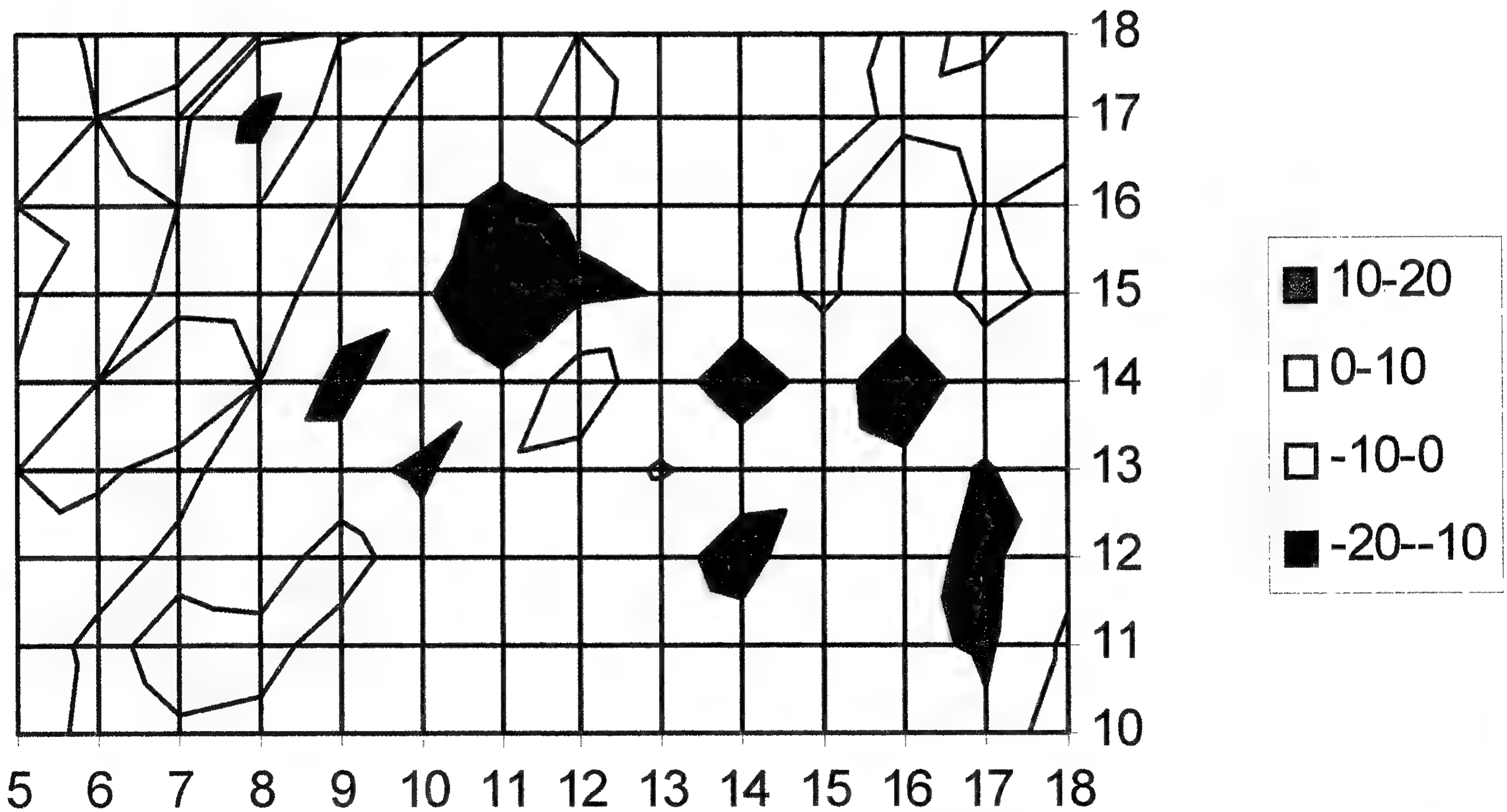

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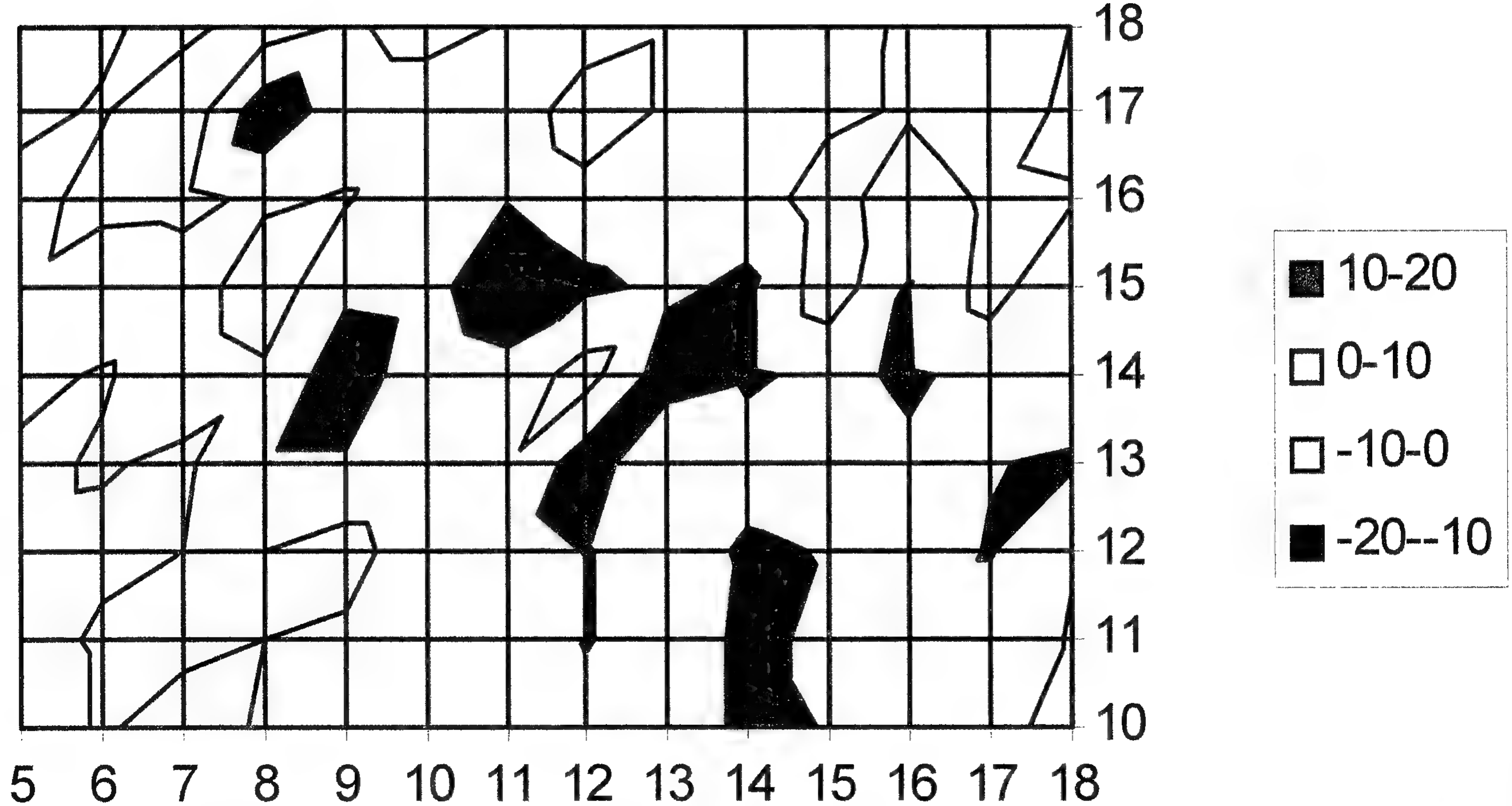

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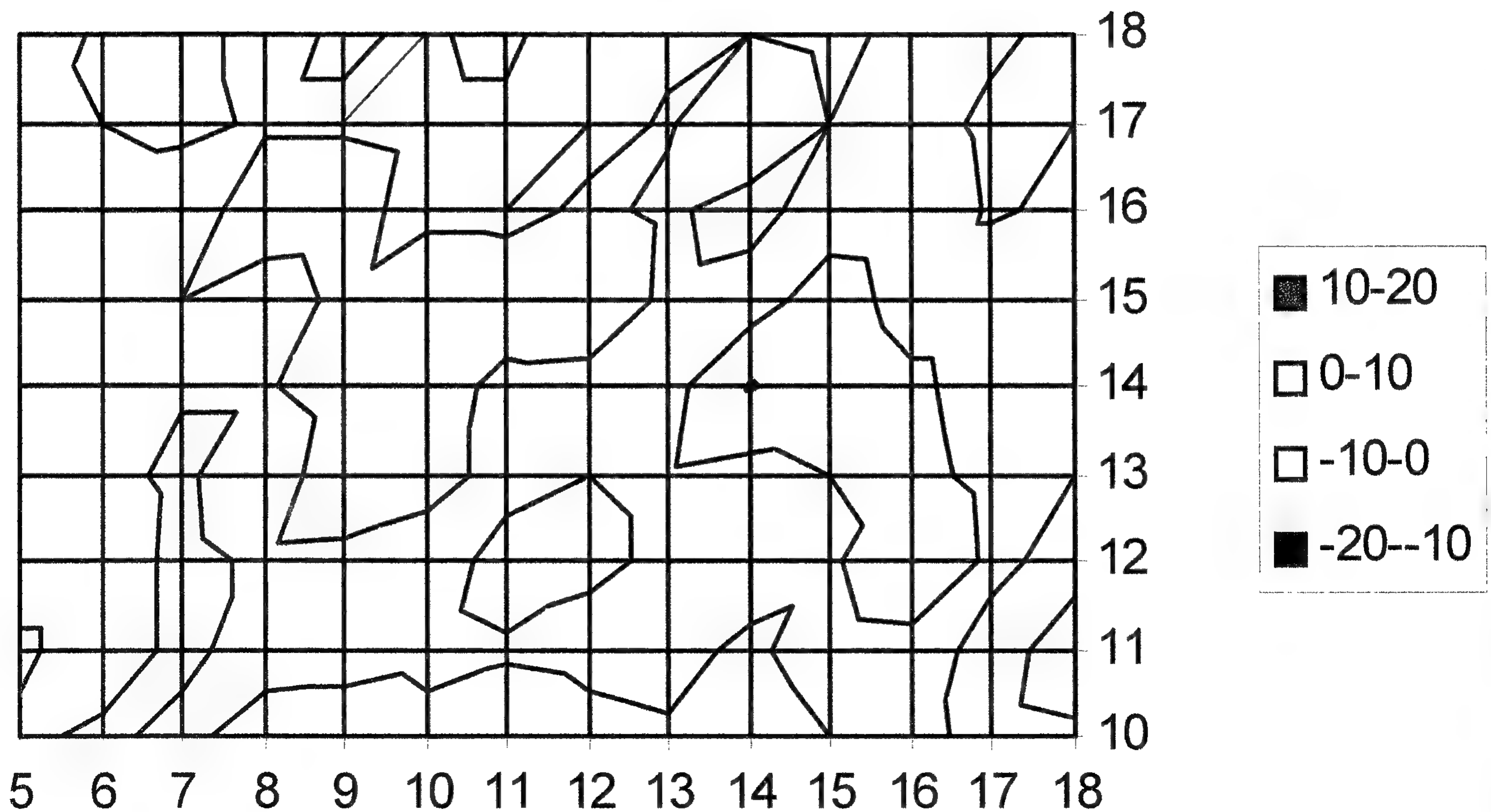

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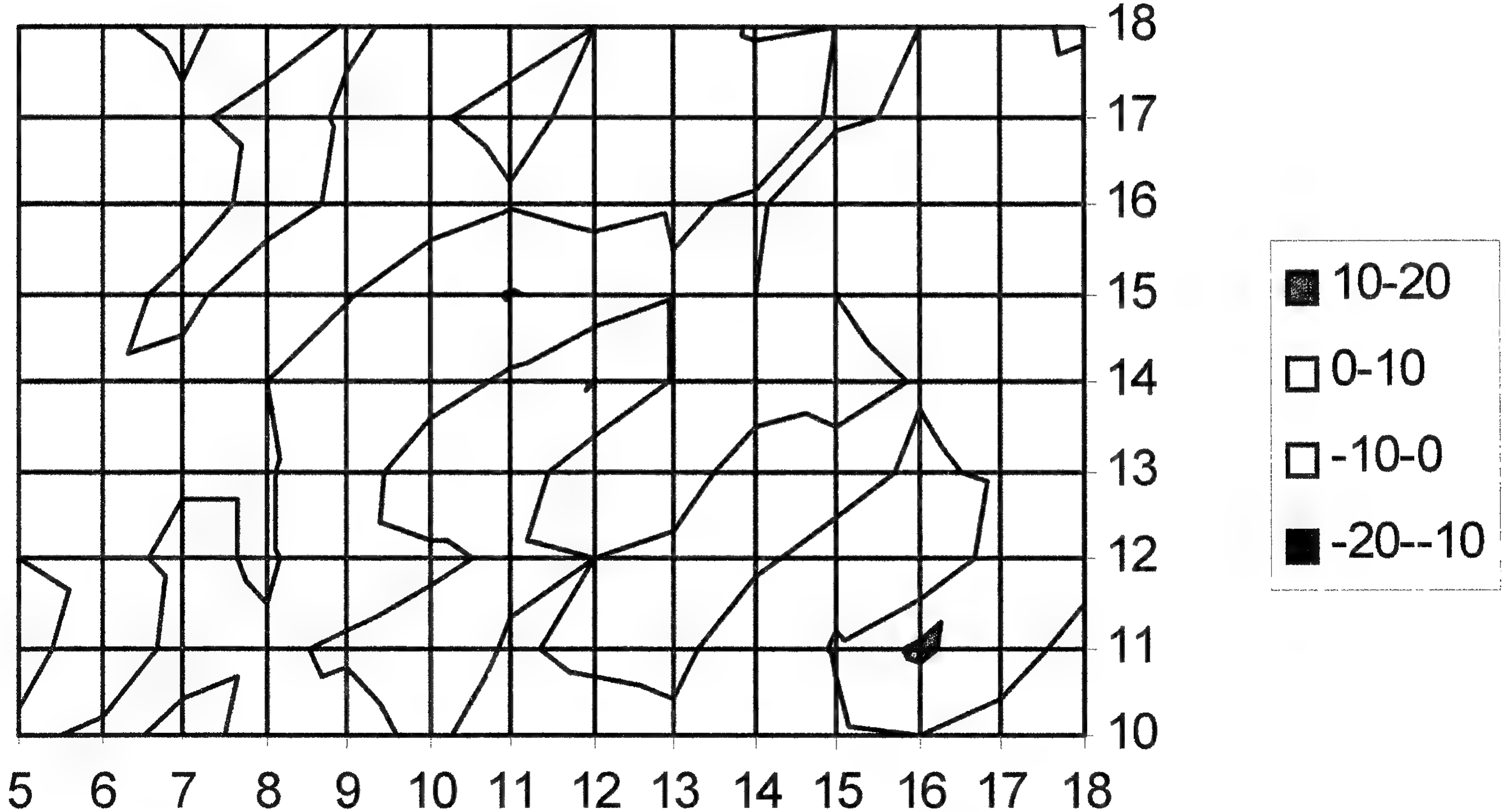

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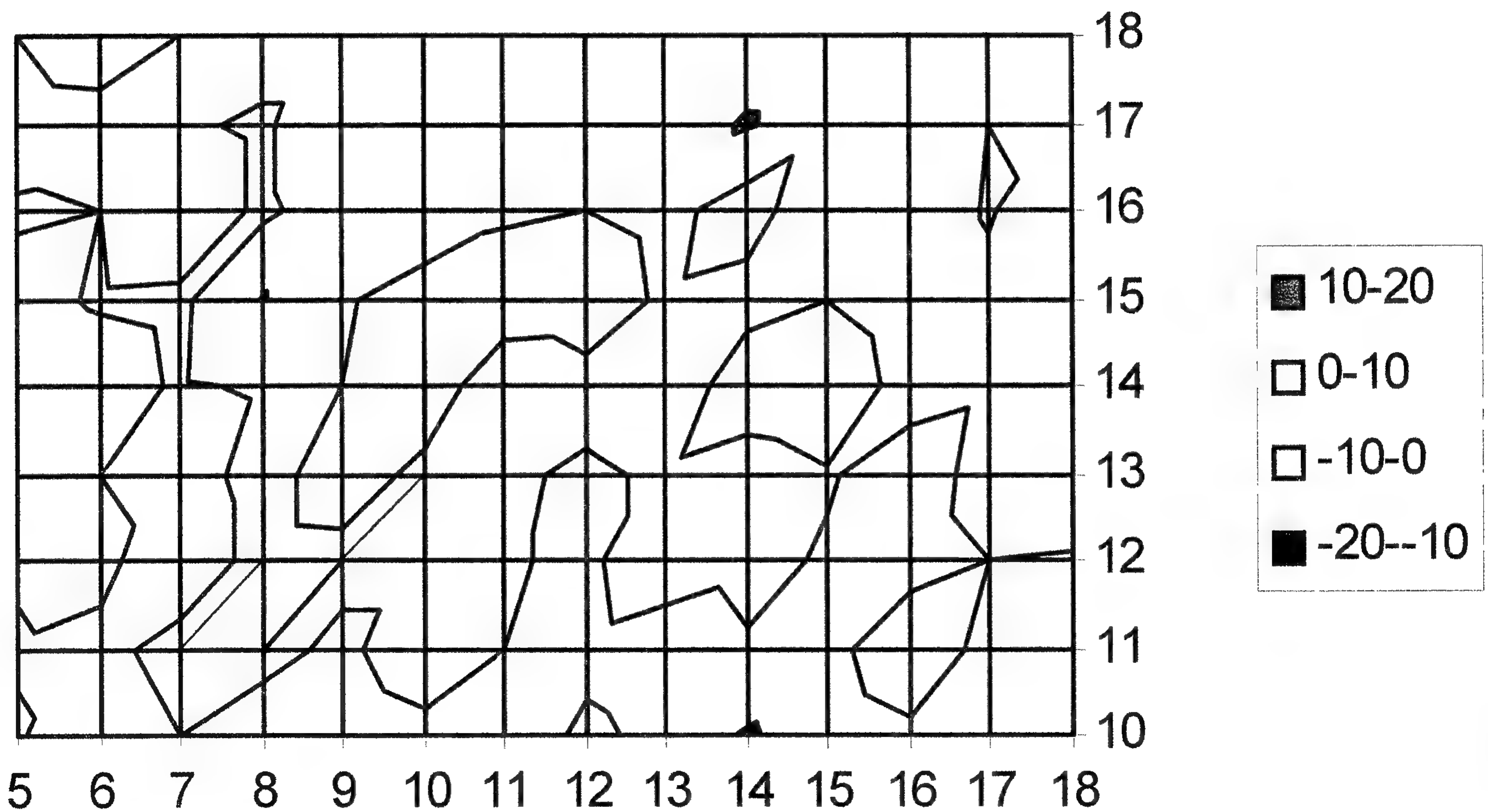
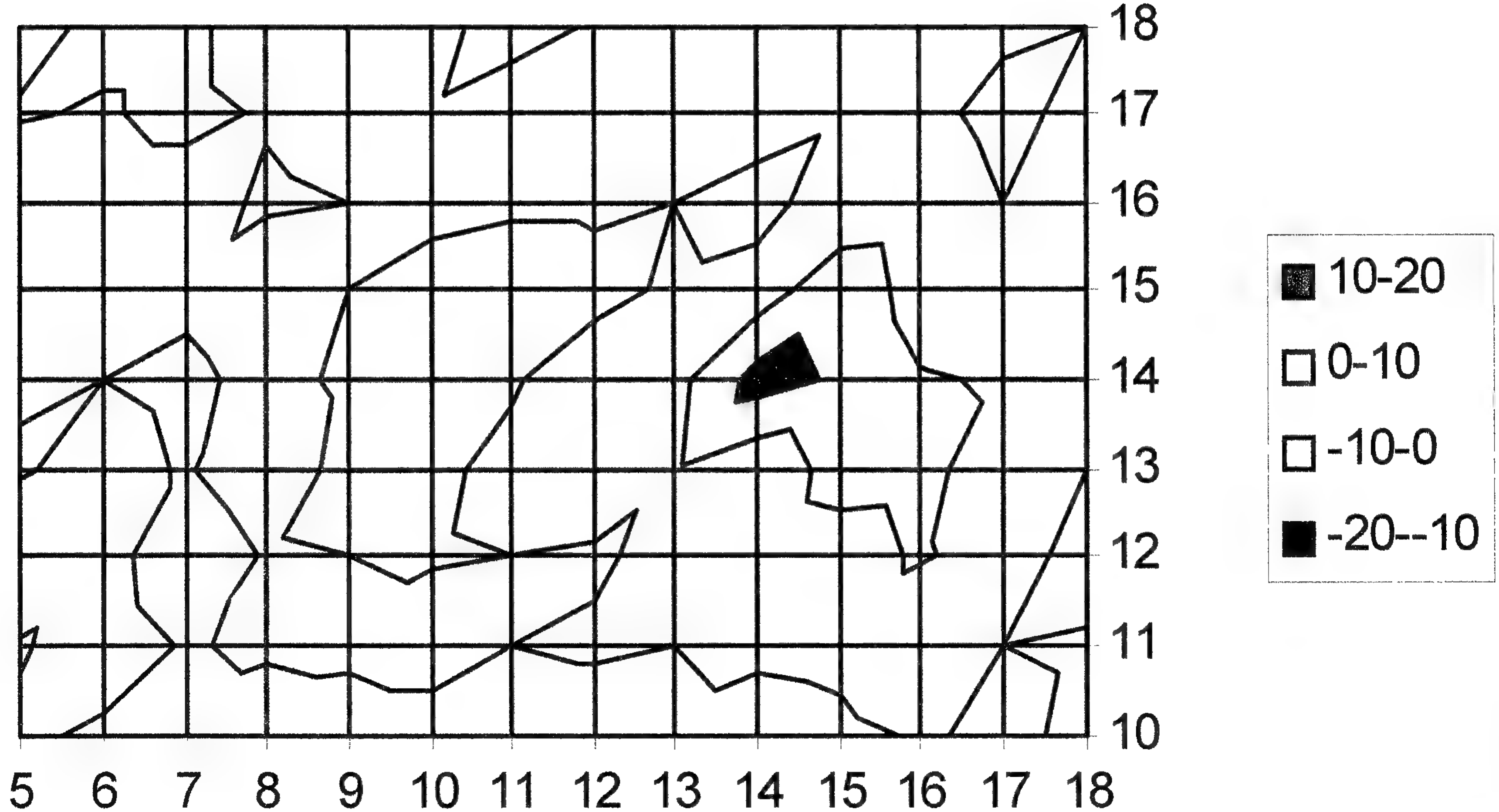


# 50%SHIFT/NORMAL: 34.23 MHZ



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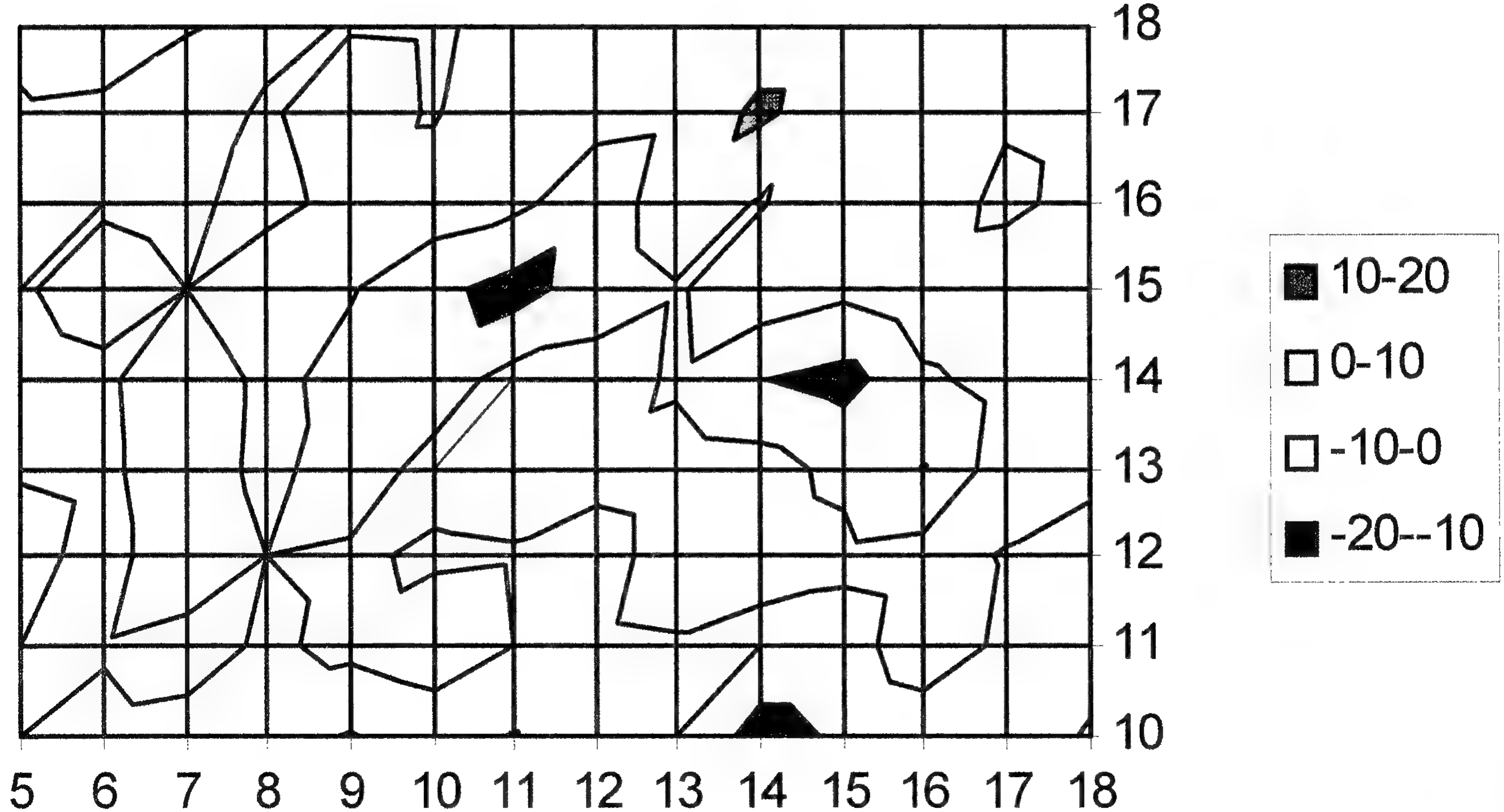

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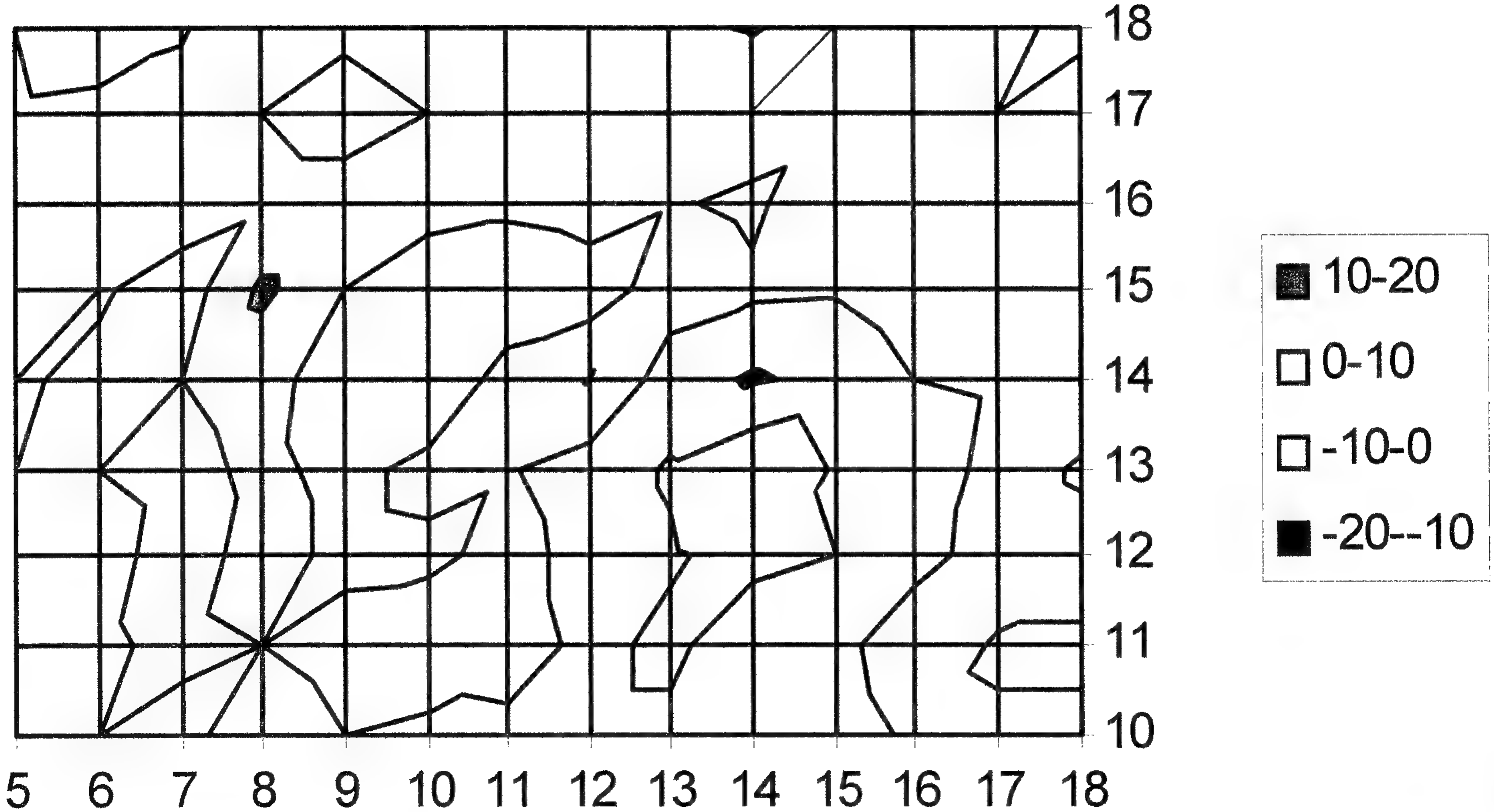

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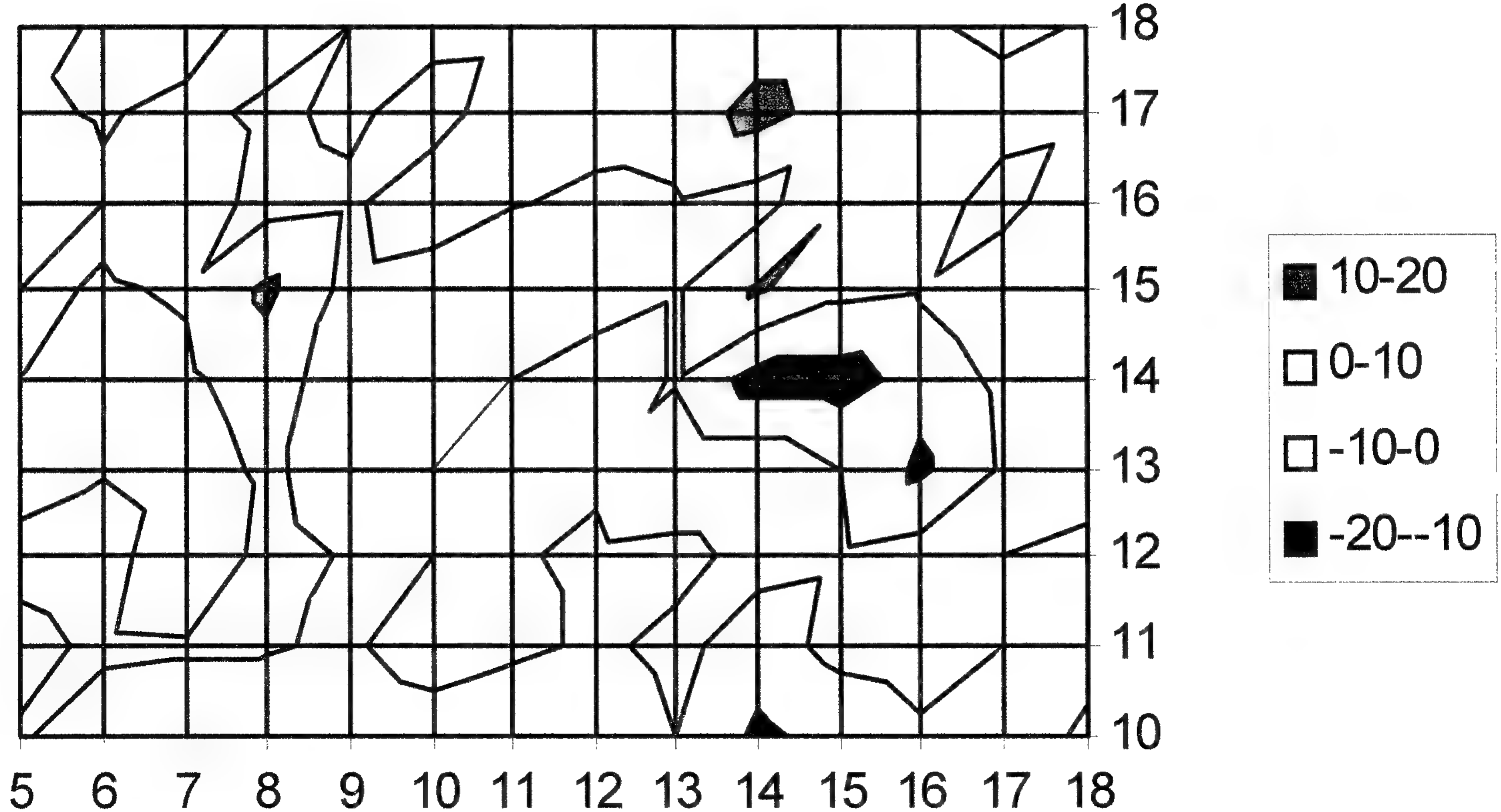

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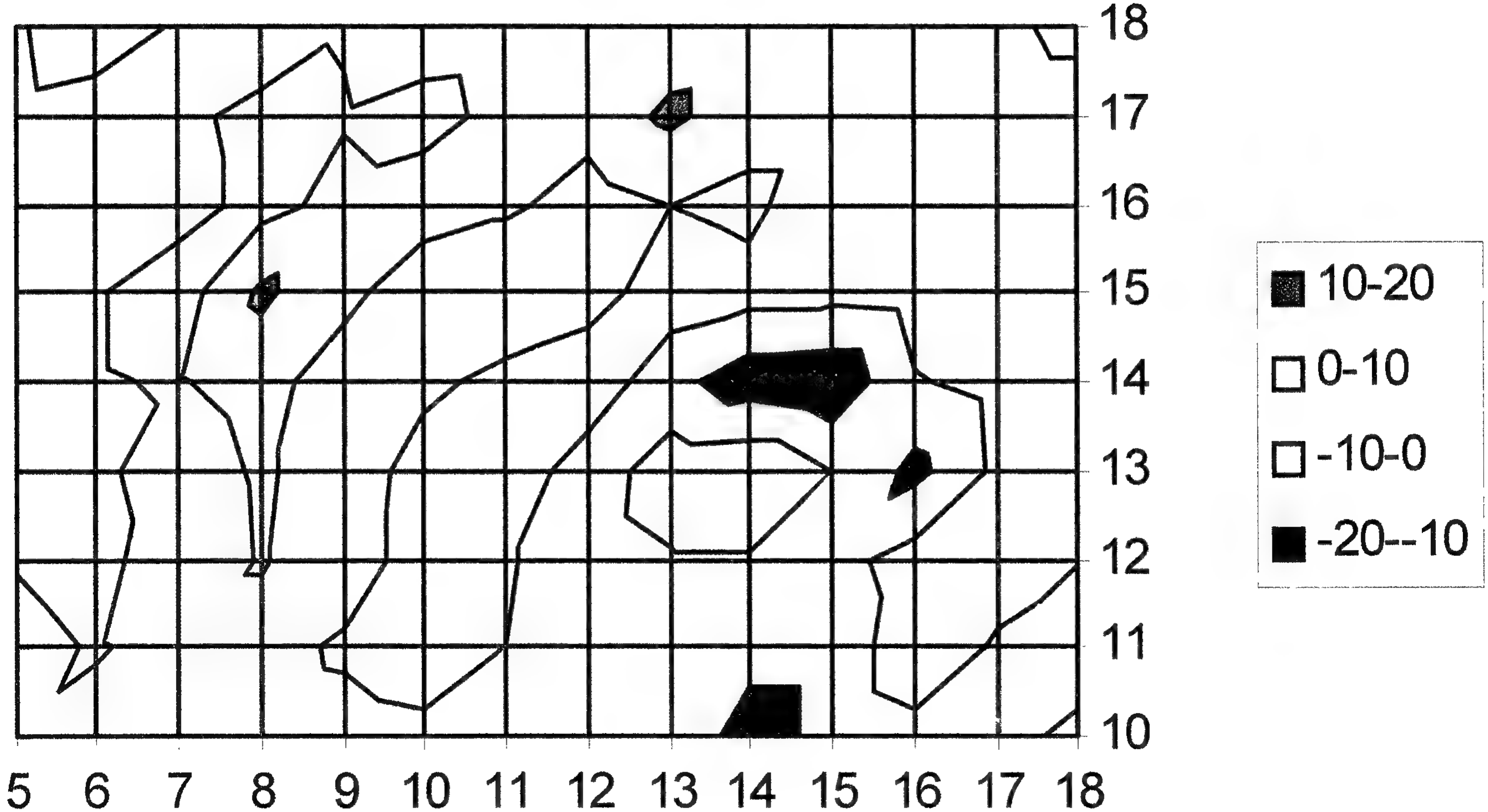

# Appendix 3

## EmscanQ Summary Report

Consider the possibility of acquiring the timing using the same technology initially utilized for acquisition of signals at electromagnetic pulse sites, a portion at a time. Set the EmscanQ to interrogate a single transducer on its array in the area of the suspected circuit fault. Connect the analog output of the EmscanQ to an analog to digital converter (ADC) or digitizing oscilloscope. Connect a lead from the suspected circuit, to a computer controlled variable delay circuit and that to the EmscanQ acquisition trigger. Control the data acquisition and storage from the same computer. This set up will allow for the acquisition of small time segments of the generated signal. With the variable delay set to zero, the acquired signal will be that which is generated the instant the trigger is initiated plus signal delay time. As the delay is varied in pre- and post trigger mode, the acquired signal will be that which is generated before and following the trigger. When these signals are integrated together over time, the result will be the entire waveform of the circuit as captured by the EmscanQ.

Comparison of the time varying signature of the nominal to suspect board will clarify timing mismatches. This acquisition will be conducted in spectral scan mode, not spatial mode. This means that acquisition will be lighting fast, and it may be possible to interrogate several transducers in a single scan.

Initial experiments will require the EmscanQ, a computer, a delay circuit, a priori knowledge of the circuit timing characteristics (normal and faulted) and a fast capture and hold ADC. The last item is critical to accurate acquisition. It may be wise to use an HP 54700 system oscilloscope. These are a family of scopes with analog input bandwidths of 1.1 to 2.0 GHz, 2 to 8 GS/s digitizing rates of 16k to 256k samples accurate to 8 bits with 12 bit averaging from 1 mV to 5 V per division. A scope of this type retails for $20k to $60k.

Upon receipt of an EmscanQ and other identified equipment (not including a digital scope) we will explore this effort in depth and identify speed and accuracy limitations.

Time related scans of potential value include:

- Extended Sample scans at a single frequency, on a single probe.
- Repetitive spatiall scans, or multispatial scans, at a single frequency.
- Repetitive spectral sweeps, or multispectral scans, on individual probes.

# Appendix 4

## Utility Driven Classifier

(Prepared by Yu, JS/SNL/'94-11-04; 844-6727 W or 268-5355 H)

This subproposal is written in support of Hewitt & Associates, Inc. in preparation of a phase-two SBIR (Small Business Innovation Research) proposal to AFLC (Air Force Logistics Command, San Antonio, TX)

### 1. Probabilistic Neural Network

1.1 Network Interconnects (Synapses)

1.2 Network Processors (Artificial Neurons)

### 2. In-Situ Training Process

2.1 Training Vectors

2.2 Training Algorithms

2.3 Value-Based Decision (Criteria)

2.4 Maximum-Information Criteria

### 3. Statistical Features and Classes

3.1 Initial and Conditional Probabilities

3.2 Joint-Likelihood Matrix

3.3 Bayes' Rule of Updating Probabilities

## 4. Image of Measured Densities

4.1 Background Noise and Clutter

4.2 Inaccuracies and Imprecisions

4.3 Sensitivity and Resolution

# SUMMARY

CBA = Circuit Board Assembly
PNN = Probabilistic Neural Network
UDC = Utility-Driven Classifier

AFLC has a large variety of circuit board assemblies (CBAs) that are critical to its mission success. THE CBAs are, therefore, of great value and their performance quality must be continuously assured. Funding the development of such quality-assurance (QA) tools for the CBAs is expected to add significant value to AFLC's future operations.

Hewitt & Associates are pleased to announce that, in our phase-one efforts sponsored by AFLC, we have successfully measured spectral densities of several CBAs using EMSCAN. These data are ready to be processed into feature-vectors for training artificial neural networks. Our phase-two efforts are to develop and implement specific procedures for transforming these data into feature-vectors with estimated parameters.

We have also completed a preliminary analysis on practically all promising paradigms of neural networks. Our measured data assure us that we need only select one of the "less-motivated" artificial neural networks that "can learn under supervision". We are hereby proposing that a ***Probabilistic Neural Network*** (PNN) be selected for our phase-two development over the backpropagation type that is an outgrowth of the original "Perceptron".

Together with requisite parallel-computing processors, the PNN and the CBA-measurement setup are to be integrated into an automated QA tool to accept, repair or reject a CBA under test. We propose to call this QA tool ***Utility-Driven Classifier*** (UDC) to meet the following guidelines:

1. The PNN should be based on well-established, probabilistic rules such as conditional probabilities, joint likelihoods and Bayes' updatings by newest measurements.

2. The UBC should give a highest probability of success in classifying similar CBAs; i.e., the classified outputs should always be global optima even for CBAs with large deviations from the training CBAs. (Backpropagation networks are more likely to be trapped in a local optimum and require human interventions to converge to a global optimum.)

3. The UBC should need no human intervention even increasing feature-dimensions and decision-complexities.

4. The UBCs' classification accuracy should not be disproportionately degraded by inadvertent or deliberate deviations in test conditions. (Because the PNN is based on Bayesian updates by new measurements, any seemingly disproportionate errors can be quickly detected and corrected.)

5. The PNN training should be virtually real-time. (One estimate gives PNN training time up to five orders of magnitude faster than backpropagation. Also, backpropagation is expected to require new and time-consuming training every time a new measurement is made.)

6. The UBC results should be based on quantified consequences of making wrong decisions such as "true-miss" in accepting a defective CBA or "false alarm" in rejecting a functional CBA. (This unique feature is called utility-driven or value-driven, because payoffs in making a correct decision and penalties in making a wrong decision are all quantified before any decisions are made.)

7. For classifying CBAs, the UBC should compete with any other classifiers in terms of values, costs, effectiveness, efficiency, accuracy, and reliability.

Our data are now indexed to three coordinates: (Abscissa, Ordinate, Frequency) = (-15 < +15; -12 < y[cm] < +12; 10 < f[MHz] < 750). They are ready to be processed into feature-vectors for training PNN.

# Appendix 5

## Windows Based Control Software for Automated Printed Circuit Board Fault Identifier System

This sub-proposal is written in support of Hewitt & Associates, Inc. in preparation of a phase-two SBIR (Small Business Innovation Research) proposal to AFLC (Air Force Logistics Command, San Antonio, Tx).

The work provided by Los Alamos National Lab would include the following:

1. **Build a Windows based software interface to the EM Scan equipment to facilitate device setup and data acquisition.** This work would most likely involve writing a low-level driver for the EM Scan equipment. We envision implementing a LabView program for the top level controls to reduce the complexity for the user. LabView has been shown in the past to also greatly reduce the development time required for a Windows application. LabView for Windows is a graphical programming language that allows the programmer to implement an instrument look and feel on the computer screen. LabView has capabilities to control the setup and operation of the equipment and also manipulate and plot the data obtained from the instrument in one or more dimensions and colors. LabView also has considerable capability for processing data with many types of pre-programmed filters and transforms. The software languages used in this task would be some combination of LabView for Windows, 'C', and possibly Interactive Data Language (IDL).

2. Provide data processing for automated EM spatial visualization of the printed circuit board assemblies and formatting the data for the Neural Network Classifier.

There are numerous methods to present the data from the EM Scan equipment to the Neural Network Classifier. If the classifier is running on a separate computer platform, the data could be transferred to the other platform through RS232, GPIB, or an Ethernet TCP/IP connection. All of these methods are supported under LabView. If the classifier and the LabView oversight program are running on the same computer platform data could be transferred via file sharing; if both programs are running under windows, Dynamic Data Exchange (DDE) could be used. There could also be a protocol set up between the classifier program and LabView, so that the LabView program would transfer the data to the classifier and wait for the return determination from the classifier. The results would be displayed as a Good/Bad indicator light on the computer screen.

3. **Design the user interface to minimize the personnel training required to operate the system.** The human interface to the system would be very simple with capability to select the board to be tested and then some switches activated by the mouse to start the board analysis. Test results would be displayed on the screen. Sub-screens would be available for the more expert user to obtain more detailed information on the particular test and the instrument setup.